中南大學 CENTRAL SOUTH UNIVERSITY

北京師範大學 BEIJING NORMAL UNIVERSITY

The 16th Workshop on Markov Processes and Related Topics

July 12-16, 2021

Central South University

Co-Chair: Mu-Fa Chen (BNU), Yong Jiao (CSU)

Local Organizer: Yong Jiao, Yuanyuan Liu, Junping Li, Zaiming Liu, Jun Peng, Jinbiao Wu

Sponsors: School of Mathematics and Statistics, HNP-LAMA, Central South University
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Supporter: Fund for Double First-Class Discipline of Central South University
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National Natural Science Foundation of China

Zoom: Meeting ID 2831393517 Passcode 0712

School of Mathematics and Statistics, Central South University

Stochastics Research Center, Beijing Normal University

中南大学数学与统计学院简介

中南大学数学与统计学院于2002年5月由原长沙铁道学院、中南工业大学、湖南医科大学的数学学科合并组建而成。学院下设数学与应用数学系、信息与计算科学系、概率与统计学系、高等数学教学研究中心、数学教学实验中心以及党政综合办公室和学生工作办公室。

学院现有教职员工132人，其中专任教师106人；教师中有教授37人、副教授及相应职称教师48人；学院拥有著名数学家侯振挺教授、解决“西塔潘猜想”的青年学者刘路研究员；入选国家及湖南省人才计划教师11人，16人担任国内外重要期刊编委及学术组织负责人。

学院于1977年开始招收培养数学专业本科学生，现有数学与应用数学、信息与计算科学、统计学3个本科专业；2012年开办数学拔尖人才培养试点班（科学班），2019年数学与应用数学专业入选国家强基计划和国家一流本科专业建设点；2020年信息与计算科学专业获批国家一流本科专业建设点；统计学专业先后获湖南省特色专业和一流本科专业建设点。学院拥有国家级精品课程2门，国家精品在线开放式课程和国际MOOC各1门，获省部级优秀教学成果奖10余项。在历届全国大学生数学竞赛、全国大学生研究生数学建模竞赛中成绩斐然。青年学者刘路在大学二年级即破解西塔潘猜想。

学院于1978年开始招收培养硕士研究生，1981年二级学科“概率论与数理统计”获批全国首批博士点并开始招收培养博士研究生。学院现有数学和统计学2个一级学科博士学位授权点、数学和统计学两个博士后科研流动站。“概率论与数理统计”学科于2001年被列为全国首批国家重点学科、且为“十五”和“十一五”国家重点学科。数学是湖南省重点建设学科，并于2017年9月入选国家“双一流”建设学科。学院学科方向涉及马氏过程及其相关领域、泛函分析及应用、常微分方程与动力系统、科学计算、偏微分方程及其应用、群论及数理逻辑、优化与控制理论、应用统计学和数量经济学等。

学院坚持立德树人，聚焦人才培养和科学研究，不断提升办学水平。近年来，学院在基础数学、应用数学以及数学在工程技术上的应用等前沿研究领域，形成了多个高水平研究团队，取得了在国际上有影响的重要研究成果。以著名数学家侯振挺教授为首的概率论与数理统计研究团队在国内外声誉卓著；侯振挺教授先后获“英国皇家戴维逊奖”和“华罗庚数学终身成就奖”；“分析数学及其应用”获批为湖南省重点实验室；“随机性数学及其应用”获批湖南省高校重点实验室。学院还先后获国家自然科学三等奖2项、国家科技进步一等奖2项、国家科技进步三等奖1项、教育部自然科学二等奖1项、湖南省光召科技奖1项、湖南省科技进步一等奖2项、湖南省自然科学一等奖2项以及其它国家级、省部级奖励20余项。

学院地处风景秀丽的岳麓山下、湘江岸边，办学历史悠久，学术气氛活跃，研究环境宽松，是潜心数学学习和研究的好地方。经过多年的发展和建设，数学学院已成为我国中部实力较强的数学研究与人才培养基地。近年来，随着“双一流”建设及中南大学建设世界知名大学的步伐不断加快，学院也在大踏步向前发展。

Schedules 会议日程

Beijing Time (GMT+8)	**July 12 (Monday)**	**July 13 (Tuesday)**	**July 14 (Wednsday)**	**July 15 (Thursday)**	**July 16 (Friday)**
Chairman	**J. P. Li**	**X. P. Guo**	**Z. M. Liu**	**Z. H. Li**	**Z. Dong**
08:00-08:30	Opening	S. Feng	X. W. Zhou	Z. Q. Chen	Y. Q. Zhao
08:30-09:00	M. F. Chen	Y. Z. Hu	D. Khoshnevisan	C. Zhu	W. Sun
09:00-09:30	H. M. Wang	Z. Q. Gao	X. C. Zhu	T. Kumagai	X. Chen
09:30-10:00	L. Wu	H. Q. Li	C. S. Deng	H. He	G. Q. Lan
10:00-10:30	Tea break	Tea break	Tea break	Tea break	Tea break
Chairman	**Y. J. Wang**	**Y. Y. Liu**	**Y. H. Zhang**	**L. T. Yan**	**F. Q. Gao**
10:30-11:00	Q. M. Shao	Y. X. Ren	L. M. Wu	J. Xiong	X. P. Guo
11:00-11:30	T. Uemura	J. H. Shao	X. D. Li	X. Y. Wu	H. J. Zhang
11:30-12:00	X. Huang	Y. Q. Wang	Y. H. Mao	R. C. Zhu	J. M. Wang
12:00-12:30			X. B. Sun		
	Lunch	Lunch	Lunch	Lunch	Lunch
Chairman	**F. B. Xi**	**Y. X. Ren**	Discussion	**J. Xiong**	**F. Y. Wang**
14:00-14:30	Y. J. Wang	F. B. XI		F. Q. Gao	T. S. Zhang
14:30-15:00	B. Wu	W. Liu		L. T. Yan	Q. Lv
15:00-15:30	D. J. Luo	C. H. Ma		L. J. Xie	V. Vatutin
15:30-16:00	D. Yao	Q. X. Zhu		D. Zhang	X. Chen
16:00-16:30	Tea break	Tea break		Tea break	Tea break
Chairman	**X. Y. Wu**	**Z. Shi**		**X. C. Zhang**	**T. S. Zhang**
16:30-17:00	C. G. Yuan	M. Röckner		S. Z. Fang	F. Y. Wang
17:00-17:30	A. Kyprianou	H. Z. Zhao		Q. S. Liu	J. Wang
17:30-18:00	J. L. Wu	Z. Vondracek		X. X. Chen	J. P. Li
	Dinner	Dinner	Dinner	Dinner	Dinner

There are POSTERS during the tea break.

Conference Venue: 134 Lecture Hall, School of Mathematics and Statisics, Central South University. Lunch and Dinner on July 15 are served at the first floor of Shang Zuo Restaurant, and at the 3rd floor of Fu Sheng Yuan Hotel for all other dates.

July 12

08:00-08:30 **Openging & Taking photos**

Chairman: Junping Li

08:30-09:00 Mu-Fa Chen (Jiangsu/Beijing Normal University, China)
Summary of Growth of Mathematical Stochastics

09:00-09:30 Huaming Wang (Anhui Normal University, China)
On maxima of random walks in varying environments

09:30-10:00 Lian Wu (Central South University, China)
Noncommutative continuous differentially subordinate martingales and applications

10:00-10:30 Tea break

Chairman: Yongjin Wang

10:30-11:00 Qiman Shao (Southern University of Science and Technology, China)
Randomized Concentration Inequalities and Applications

11:00-11:30 Toshihiro Uemura (Kansai University, Japan)
Some Estimates of Symmetric α-Stable type Processes with Singular/ Degenerate Lévy Densities

11:30-12:00 Xing Huang (Tianjin University, China)
Mean-field CKLS model

July 12

Chairman: Fubao Xi

14:00-14:30 Yongjin Wang (Nankai University, China)
On a class of stochastic wave equations driven by stable space-time noises

14:30-15:00 Bo Wu (Fudan University, China)
Li-Yau Harnack inequality in a manifold with a non-convex boundary

15:00-15:30 Dejun Luo (AMSS, Chinese Academy of Sciences, China)
Dissipation enhancement for stochastic heat equation with transport noise

15:30-16:00 Dong Yao (Jiangsu Normal University, China)
Mean Field Behavior during the Big Bang for Coalescing Random Walk

16:00-16:30 Tea break

Chairman: Qiman Shao

16:30-17:00 Chenggui Yuan (Swansea University, UK)
Distribution dependent SDEs driven by fractional Brownian motions

17:00-17:30 Andreas Kyprianou (University of Bath, UK)
Asymptotic moments of spatial branching processes

17:30-18:00 Jianglun Wu (Swansea University, UK)
Ergodicity for 2D stochastic Burgers equation

July 13

Chairman: Xianping Guo

08:00-08:30 Shui Feng (McMaster University, Canada)
Large Deviations for Randomly Weighted Random Measures

08:30-09:00 Yaozhong Hu (University of Alberta at Edmonton, Canada)
Stochastic heat equation with general nonlinear spatial rough Gaussian noise

09:00-09:30 Zhiqiang Gao (Beijing Normal University, China)
A second order expansion in the local limit theorem for a symmetric irreducible branching random walk

09:30-10:00 Huaiqian Li (Tianjin University, China)
Li–Yau Inequalities for Dunkl Heat Equations

10:00-10:30 Tea break

Chairman: Yuanyuan Liu

10:30-11:00 Yanxia Ren (Peking University, China)
Convergence rate for a class of supercritical superprocesses

11:00-11:30 Jinghai Shao (Tianjin University, China)
The delay-dependent control problem for finite-horizon continuous-time decision process

11:30-12:00 Yanqing Wang (Zhongnan University of Economics and Law, China)
Berry-Esseen's bound and Cramér's large deviation expansion for a supercritical branching process with immigration in a random environment

July 13

Chairman: Yanxia Ren

14:00-14:30 Fubao Xi (Beijing Institute of Technology, China)
Distribution dependent jump processes with random switching

14:30-15:00 Wei Liu (Jiangsu Normal University, China)
Time-Fractional SPDE

15:00-15:30 Chunhua Ma (Nankai University, China)
Limit theorems for continuous-state branching processes with immigration

15:30-16:00 Quanxin Zhu (Hunan Normal University, China)
Stability analysis of stochastic differential equations with semi-Markov switching

16:00-16:30 Tea break

Chairman: Zhan Shi

16:30-17:00 Michael Röckner(Bielefeld University, DE)
Equilibria of nonlinear distorted Brownian motions

17:00-17:30 Huaizhong Zhao (Durham University, UK)
Ergodicity of Periodic and Quasi-Periodic Measures

17:30-18:00 Zoran Vondracek (University of Zagreb, CROATIA)
On boundary decay of harmonic functions, green kernels and heat kernels for dome non-local operators

July 14

Chairman: Zaiming Liu

08:00-08:30 Xiaowen Zhou (Concordia University, CA)
Boundary Behaviors at ∞ for Fragments in Simple Exchangeable Fragmentation-Coalescence Processes

08:30-09:00 Davar Khoshnevisan (University of Utah, USA)
Phase analysis of a family of stochastic reaction-diffusion equations

09:00-09:30 Xiangchan Zhu (Chinese Academy of Sciences, China)
Singular kinetic equations and applications

09:30-10:00 Changsong Deng (Wuhan University, China)
Singular integrals of subordinators and applications to SPDEs

10:00-10:30 Tea break

Chairman: Yuhui Zhang

10:30-11:00 Liming Wu (HIT, China and UCA, France)
Exponential convergence of mean-field interacting particle systems and the McKean-Vlasov equation

11:00-11:30 Xiangdong Li (AMSS, Chinese Academy of Sciences, China)
On the incompressible Naiver-Stokes equation via optimal transport problem

11:30-12:00 Yonghua Mao (Beijing Normal University, China)
Revisit of L.-K.HUA's theory on input-output models

12:00-12:30 Xiaobin Sun (Jiangsu Normal University, China)
Averaging principle for slow-fast stochastic system driven by α-stable processes

July 15

Chairman: Zenghu Li

08:00-08:30 Zhenqing Chen (University of Washington, USA)
SDEs driven by multiplicative Lévy processes

08:30-09:00 Chao Zhu (University of Wisconsin-Milwaukee)
Regime-Switching Jump-Diffusion Processes with Countable Regimes

09:00-09:30 Takashi Kumagai (Kyoto University, Japan)
Quenched and averaged tails of the heat kernel of the two-dimensional uniform spanning tree

09:30-10:00 Hui He (Beijing Normal University, China)
Some properties of a stationary continuous state branching process

10:00-10:30 Tea break

Chairman: Litan Yan

10:30-11:00 Jie Xiong (Southern University of Science and Technology, China)
Indefinite Backward Stochastic Linear-Quadratic Optimal Control Problems

11:00-11:30 Xianyuan Wu (Capital Normal University, China)
A Note On the Asymptotic Behavior of the Height for a Birth-and-Death Process

11:30-12:00 Rongchan Zhu (Beijing Institute of Technology, China)
Large N Limit of the $O(N)$ Linear Sigma Model via Stochastic Quantization

July 15

Chairman: Jie Xiong

14:00-14:30 Fuqing Gao (Wuhan Universtiy, China)
Scaling limits of directed polymers in spatial-correlated environment

14:30-15:00 Litan Yan (Donghua University, China)
Some limit theorems associated with integral functionals of fBm

15:00-15:30 Longjie Xie (Jiangsu Normal University, China)
Limit theorems for multiscale stochastic dynamical systems

15:30-16:00 Deng Zhang (Shanghai Jiao Tong University, China)
On the multi-bubble blow-up solutions to stochastic nonlinear Schrödinger equations

16:00-16:30 Tea break

Chairman: Xicheng Zhang

16:30-17:00 Shizan Fang (University of Burgundy, France)
Brownian motion and NS equations

17:00-17:30 Quansheng Liu (Univ. Bretagne-Sud, France)
A Kesten-Stigum type theorem for a super-critical multi-type branching process in a random environment

17:30-18:00 Xinxin Chen (University Claude Bernard Lyon 1, France)
Number of births on the negative half-line in binary BBM

July 16

Chairman: Zhao Dong

08:00-08:30 Yiqiang Zhao (Carleton University, Canada)
Large-Scale and Large-Time Behaviour of Mean-Field Interacting Particle Systems on Block-structured Networks

08:30-09:00 Wei Sun (Concordia University, Canada)
Periodic solutions of hybrid jump diffusion processes

09:00-09:30 Xin Chen (Shanghai Jiao Tong University, China)
The existence of quasi-invariance flow on loop space over a non-compact Riemannian manifold

09:30-10:00 Guangqiang Lan (Beijing University of Chemical Technology)
Strong convergence and asymptotic exponential stability of modified truncated EM method for neutral stochastic differential equations with time-dependent delay

10:00-10:30 Tea break

Chairman: Fuqing Gao

10:30-11:00 Xianping Guo (Sun Yat-Sen University, China)
Constrained PDMDPs on finite horizon

11:00-11:30 Hanjun Zhang (Xiangtan University, China)
Quasi-stationary distributions for Markov chains

11:30-12:00 Jieming Wang (Beijing Institute of Technology)
Green function estimates for second order elliptic operator in non-divergence form

July 16

Chairman: Fengyu Wang

14:00-14:30 Tusheng Zhang (University of Manchester, UK)
Global well-posedness of stochastic reaction-diffusion equations on the whole real line with logarithmic nonlinearity driven by space-time white noise

14:30-15:00 Qi Lv (Sichuan University, China)
Observability Problem for Some Stochastic Partial Differential Equations

15:00-15:30 Vladimir Vatutin (Steklov International Mathematical Center, Russia)
Galton-Watson branching processes with countably many types and infinite second moments

15:30-16:00 Xian Chen (Xiamen University, China)
Nonzero-sum expected average discrete-time stochastic games

16:00-16:30 Tea break

Chairman: Tusheng Zhang

16:30-17:00 Fengyu Wang (Beijing Normal University/Tianjin University, China)
Wasserstein Limit for Empirical Measures of Diffusion Processes

17:00-17:30 Jian Wang (Fujian Normal University, China)
Heat kernel upper bounds for symmetric Markov processes

17:30-18:00 Junping Li (Central South University, China)
The down/up crossing properties of Markov branching processes

Posters 会议墙报

Man Chen (Capital Normal University, China)
A Wiener-Hopf factorization related potential measure for diffusion processes

Zengcai Chen (Beijing Normal University, China)
Lower deviation probability for the maximum of a branching random walk

Junxia Duan (Central South University, China)
The probabilistic solution of a system of semilinear elliptic PDEs under the third boundary conditions

Bingzhen Geng (Central South University, China)
On asymptotic finite-time ruin probabilities of a new bidimensional risk model with constant interest force and dependent claims

Wendi Li (Central South University, China)
Quasi-stationary behavior for Markov-modulated Markov chains

Shengli Liang (Beijing Normal University, China)
Conditional L^1-convergence for the martingale of a critical branching process in random environment

Jiawei Liu (Beijing Normal University, China)
A scaling limit theorem for Galton-Watson in varying environments

Yingchun Tang (Central South University, China)
Extinguishing Behaviors for Continuous-State Nonlinear Branching Processes

Tao Wang (Beijing Normal University, China)
Exponential and strong ergodicity for time-changed symmetric stable processes

Zhexin Wen (Central South University, China)
Two-time-scale Regime-Switching Stochastic Kolmogorov Systems with Wideband Noises

Jingchuan Zhang (Central South University, China)
Optimal cost mechanisms in queues

Yaping Zhu (Beijing Normal University, China)
A Law of Large Numbers for the absorbed mass of super Brownian motion with immigration

Abstracts 会议摘要

SUMMARY OF GROWTH OF MATHEMATICAL STOCHASTICS

Mu-Fa CHEN *Jiangsu/Beijing Normal University, China*, E-mail: mfchen@bnu.edu.cn

Abstract: This talk summarizes the growth and maturity of mathematical stochastics, mainly in the mainland of China. It includes two periods of early history, the syllabus of "College Mathematics" for non-mathematics majors facing the new century, the teaching materials and research institutions of "mathematical stochastics", the mark of the maturity of mathematical stochastics, etc.

Because this report is devoted mainly to the scholars working in China, we will use Chinese in the talk. The corresponding article in Chinese will be published in the coming October in "Chinese Journal of Applied Probability and Statistics". For the convenience of foreign friends, an Ebglish translation of the article is now available at
http://math0.bnu.edu.cn/~chenmf/main_eng.htm

ON MAXIMA OF RANDOM WALKS IN VARYING ENVIRONMENTS

Hua-Ming WANG *Anhui Normal University, China*, E-mail: hmking@ahnu.edu.cn

Abstract: Consider random walks in varying environments with asymptotically zero drifts on the lattice of positive half line. For the nearest neighbor random walk, (2,1) random walk and (1,2) random walk, we get some delicate limit theories of distributions of their maxima of a positive excursion, which are quite different from the ones of simple random walks. Asymptotics of both the tail and critical tail sequences of continued fractions play important roles in our studies.

NONCOMMUTATIVE CONTINUOUS DIFFERENTIALLY SUBORDINATE MARTINGALES AND APPLICATIONS

Lian WU *Central South University, China*, E-mail: wulian@csu.edu.cn

Abstract: We introduce the notion of differential subordination in the context of noncommutative continuous-time martingales and show that for $2 < p < \infty$ this domination enforces the corresponding L^p bound between the two processes. As applications, we obtain best-order L^p inequalities for the second-order Riesz transforms on a class of group von Neumann algebras equipped with a conditionally negative length function. Our approach highlights the fruitful interplay between the noncommutative probability theory and the noncommutative harmonic analysis.

RANDOMIZED CONCENTRATION INEQUALITIES AND APPLICATIONS

Qi-Man SHAO *Southern University of Science and Technology, China*, E-mail: shaoqm@sustech.edu.cn

Abstract: Randomized concentration inequalities play an important role in dealing with distribution approximation for non-linear statistics. In this talk, we will review some recent developments on randomized concentration inequalities. Especially, a randomized concentration inequality with application to non-linear statistics in R^d will be discussed.

SOME ESTIMATES OF SYMMETRIC α-STABLE TYPE PROCESSES WITH SINGULAR/DEGENERATE LÉVY DENSITIES

Toshihiro UEMURA *Kansai University, Japan*, E-mail: t-uemura@kansai-u.ac.jp

Abstract: We are concerned with a symmetric α-stable type process with a Lévy density so that it may be singular or degenerate at 0. We first discuss about the conservativeness of the process, then consider a precise expression of the infinitesimal generator and its "core". In particular, test functions, the set of smooth functions with compact support may not be appropriate as its "core" because of the singularities at 0 of the Lévy density, and instead we introduce a class of smooth functions. This is a joint work with Masayoshi Takeda (Kansai University).

MEAN-FIELD CKLS MODEL

Xing HUANG *Tianjin University, China*, E-mail: xinghuang@tju.edu.cn

Abstract: In this paper, the strong well-posedness for one-dimensional mean-field SDEs with linear drift and distribution dependent and Hölder continuous diffusion is obtained. Moreover, the exponential ergodicity in Wasserstein distance is also investigated. In addition, Wang's log-Harnack type inequality is derived for mean-field CKLS model, where the solution is non-negative provided so is the initial value.

ON A CLASS OF STOCHASTIC WAVE EQUATIONS DRIVEN BY STABLE SPACE-TIME NOISES

Yongjin WANG *Nankai University, China*, E-mail: yjwang@nankai.edu.cn

Abstract: In this talk, we address a class of stochastic wave equations driven by stable space-time noises, but with non-Lipschitz coefficients. We shall construct a weak convergence procedure and demonstrate the existence of weak mild solutions on this class of SPDEs.

Li-Yau Harnack inequality in a manifold with a non-convex boundary

Bo WU *Fudan University, China*, E-mail: wubo@fudan.edu.cn

Abstract: In this talk, we will introduce the differential harnack inequality for each $h \in H$ on the Riemannian path space over a manifold(possible with a boundary), theses inequalities extend and strengthen the recent results derived by Haslhofer-Kopfer-Naber for the case of manifolds without boundaries. As a application, from which we may obtain the Li-Yau Harnack inequality in a Ricci-flat manifold with a boundary, in particular, when the boundary is not convex, our work is new. In addition, we also obtain the associated differential harnack inequality for the O-U processor on the Riemannian path space.

DISSIPATION ENHANCEMENT FOR STOCHASTIC HEAT EQUATION WITH TRANSPORT NOISE

Dejun LUO *AMSS, Chinese Academy of Sciences, China*, E-mail: luodj@amss.ac.cn

Abstract: We will show the phenomenon of dissipation enhancement for stochastic heat equations on the torus with multiplicative transport noise, by making use of the mild formulation and properties of heat semigroup. Moreover, the dissipation rate can be as large as possible for suitable parameters of the noise. This talk is based on joint work with Professor Franco Flandoli and Doctor Lucio Galeati.

MEAN FIELD BEHAVIOR DURING THE BIG BANG FOR COALESCING BRANCHING WALK

Dong YAO *Jiangsu Normal University, China*, E-mail: wonderspiritfall@gmail.com

Abstract: In this talk we consider the coalescing random walk model on general graphs $G = (V, E)$. Initially every vertex of G has a particle. Each particle performs independent random walk. Whenever two particles meet, they merge into one particle which continues to perform random walk. We set up a unified framework to study the leading order of decay rate of P_t, the expectation of the fraction of occupied sites at time t, particularly for the 'Big Bang' regime where $t \ll t_{\text{coal}} := \mathbf{E}[\inf\{s : \text{There is only one particle at time } s\}]$. Our results show that P_t satisfies certain 'mean field behavior', if the graphs satisfy certain 'transience-like' conditions. We apply this framework to two families of graphs: (1) graphs given by configuration model with degree ≥ 3, and (2) finite and infinite vertex-transitive graphs. In the first case, we show that for $1 \ll t \ll |V|$, P_t decays in the order of t^{-1}, and $(tP_t)^{-1}$ is approximately the probability that two particles starting from the root of the corresponding unimodular Galton-Watson tree never collide after one of them leaves the root, which is also roughly $|V|/(2t_{\text{meet}})$, where t_{meet} is the mean meeting time of two independent walkers. By taking the local weak limit, for the corresponding unimodular Galton-Watson tree we prove convergence of tP_t as $t \to \infty$. For the second family of graphs, if we take a growing sequence of finite vertex-transitive graphs $G_n = (V_n, E_n)$, such that $t_{\text{meet}} = O(|V_n|)$, and the inverse of the spectral gap t_{rel} is $o(|V_n|)$, we show for $t_{\text{rel}} \ll t \ll t_{\text{coal}}$, $(tP_t)^{-1}$ is approximately the probability that two random walks never meet before time t, and also $|V|/(2t_{\text{meet}})$. In addition, we define a certain natural 'uniform transience' condition, and show that in the transitive setup it implies the above for

all $1 \ll t \ll t_{\text{coal}}$. Such estimates of tP_t are also obtained for all infinite transient transitive unimodular graphs, in particular, all transient transitive amenable graphs. Based on joint work with Jonathan Hermon, Shuangping Li and Lingfu Zhang.

DISTRIBUTION DEPENDENT SDEs DRIVEN BY FRACTIONAL BROWNIAN MOTIONS

Chenggui YUAN *Swansea University, UK*, E-mail: c.yuan@swansea.ac.uk

Abstract: In this presentation, a class of distribution dependent stochastic differential equations driven by fractional Brownian motions with Hurst parameter $H \in (1/2, 1)$ is investigated. The well-posedness of this type equations is proved, and a general result on the Bismut formula for the Lions derivative is established. As applications, we provide the Bismut formulas of this kind for both non-degenerate and degenerate cases, and obtain the estimates of the Lions derivative and the total variation distance between the laws of two solutions. This is a joint work with Xiliang Fan, Xing Huang and Yongqiang Suo.

References

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ASYMPTOTIC MOMENTS OF SPATIAL BRANCHING PROCESSES

Andreas KYPRIANOU *University of Bath, UK*, E-mail: a.kyprianou@bath.ac.uk

Abstract: Suppose that $X = (X_t, t \geq 0)$ is either a superprocess or a branching Markov process on a general space E, with non-local branching mechanism and probabilities P_{δ_x}, when issued from a unit mass at $x \in E$. For a general setting in which the first moment semigroup of X displays a Perron-Frobenius type behaviour, we show that, for $k \geq 2$ and any positive bounded measurable function f on E,

$$\lim_{t\to\infty} g(t) E_{\delta_x}[\langle f, X_t\rangle^k] = C_k(x, f)$$

where the constant $C_k(x, f)$ can be identified in terms of the principal right eigen-function and left eigen-measure and $g(t)$ is an appropriate determinisitic normalisation, which can be

identified explicitly as either polynomial in t or exponential in t, depending on whether X is a critical, supercritical or subcritical process. This is based on joint work with Emma Horton and Isaac Gonzalez.

ERGODICITY FOR 2D STOCHASTIC BURGERS EQUATION

Jianglun WU *Swansea University, UK*, E-mail: j.l.wu@swansea.ac.uk

Abstract: This talk is concerned with 2D (vector-valued) stochastic Burgers equation driven by cylindrical Brownian motion over a bounded space domain. By introducing a transformation, we are able to link the stochastic Burgers equation with a random partial differential equation, which enable us to establish the existence and uniqueness of invariant measures for the concerned 2D stochastic Burgers equation. Furthermore, we show the existence of a trivial stationary solution which is exponentially stable. The talk is based on a recent joint work with Zhao Dong and Guoli Zhou.

LARGE DEVIATIONS FOR RANDOMLY WEIGHTED RANDOM MEASURES

Shui FENG *McMaster University, Canada, E-mail: shuifeng@mcmaster.ca*

Abstract: Let $\{\mathcal{Z}_n : n \geq 1\}$ be a sequence of i.i.d. random probability measures. Independently, for each $n \geq 1$, let $(X_{n1}, \ldots, X_{nn})$ be a random vector of positive random variables that add up to one. The large deviation principles are established for the randomly weighted sum $\sum_{i=1}^{n} X_{ni}\mathcal{Z}_i$. As applications, we obtain the large deviation principles for a class of randomly weighted means including the Dirichlet mean and the corresponding posterior mean.

STOCHASTIC HEAT EQUATION WITH GENERAL NONLINEAR SPATIAL ROUGH GAUSSIAN NOISE

Yaozhong HU *University of Alberta at Edmonton, Canada*, E-mail: yaozhong@ualberta.ca

Abstract: In this talk, we consider the following one dimensional (in space variable) nonlinear stochastic heat equation driven by the Gaussian noise which is white in time and fractional in space:

$$\frac{\partial u(t,x)}{\partial t} = \frac{\partial^2 u(t,x)}{\partial x^2} + \sigma(u(t,x))\dot{W}(t,x),$$

where $W(t,x)$ s a centered Gaussian process with covariance given by

$$\mathbf{E}[W(t,x)W(s,y)] = \frac{1}{2}\left(|x|^{2H} + |y|^{2H} - |x-y|^{2H}\right)(s \wedge t).$$

Here the Hurst parameter H is between 1/4 and 1/2 and $\dot{W}(t,x) = \frac{\partial^2 W}{\partial t \partial x}$. We remove the technical condition $\sigma(0) = 0$ previously assumed. The idea is to introduce a weight for the solution.

When $\sigma(t,u)$ is a constant the solution is a Gaussian random field and we obtain the bound of the solution $\sup_{0\le t\le T,|x|\le L}|u(t,x)|$ when T and L goes to infinity. This is a joint work with Xiong Wang.

A SECOND ORDER EXPANSION IN THE LOCAL LIMIT THEOREM FOR A SYMMETRIC IRREDUCIBLE BRANCHING WALK

Zhi-Qiang GAO *Beijing Normal University, China*, E-mail: gaozq@bnu.edu.cn

Abstract: Consider a branching random walk, where the branching mechanism is governed by a Galton-Watson process, and the migration by a finite range symmetric irreducible random walk on the integer lattice $\mathbb{Z}^d$. Let $Z_n(z)$ be the number of the particles in the n-th generation at the point $z\in\mathbb{Z}^d$. Under the mild moment conditions for offspring distribution of the underlying Galton-Watson, we derive a second order expansion in the local limit theorem for $Z_n(z)$ for each given $z\in\mathbb{Z}^d$. That generalizes the results for simple branching random walks obtained by Gao [2018, SPA].

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LI–YAU INEQUALITIES FOR DUNKL HEAT EQUATIONS

Huaiqian LI *Tianjin University, China*, E-mail: huaiqianlee@gmail.com

Abstract: The Dunkl Laplacian is a non-local operator parameterized by reflection groups and multiplicity functions. We will talk about Li–Yau inequalities for the heat equation associated to the Dunkl Laplacian.

CONVERGENCE RATE FOR A CLASS OF SUPERCRITICAL SUPERPROCESSES

Yan-Xia REN *Peking University, China*, E-mail: yxren@math.pku.edu.cn

Abstract: Suppose $X=\{X_t,t\ge 0\}$ is a supercritical superprocess. Let ϕ be the eigenfunction of the mean semigroup of X corresponding to principal eigenvalue $\lambda>0$. Then $M_t(\phi)=e^{-\lambda t}\langle\phi,X_t\rangle, t\ge 0$, is a non-negative martingale with almost sure limit $M_\infty(\phi)$. In this paper

we study the rate at which $M_t(\phi) - M_\infty(\phi)$ converges to 0 as $t \to \infty$ when the process may not have finite variance. Under some conditions on the mean semigroup, we provide sufficient conditions and necessary conditions for the rate in the almost sure sense. Some results on the convergence rate in L^p with $p \in (1, 2)$ are also obtained.

THE DELAY-DEPENDENT CONTROL PROBLEM FOR FINITE-HORIZON CONTINUOUS-TIME DECISION PROCESS

Jinghai SHAO *Tianjin University, China*, E-mail: shaojh@tju.edu.cn

Abstract: This work investigates the optimal control problem for the continuous-time decision processes with an enlarged class of control policies, i.e. delay-dependent control policies. We show that, under certain mild conditions, among the class of delay-dependent control policies, there is an optimal one which is Markovian. Such result is obtained by characterizing the value function to be a unique viscosity solution to certain HJB equation. To this end, we first prove the existence of the optimal delay-dependent controls by developing the compactification method. Then we use the optimal controls to establish the dynamic programming principle and HJB equations. Finally, the comparison principle for the HJB equation is proposed to show the uniqueness of the viscosity solution.

BERRY-ESSEEN'S BOUND AND CRAMÉR'S LARGE DEVIATION EXPANSION FOR A SUPERCRITICAL BRANCHING PRCESS WITH IMMIGRATION IN A RANDOM ENVIRONMENT

Yanqing WANG *Zhongnan University of Economics and Law, China*, E-mail: yanqingwang102@163.com

Abstract: We consider a supercritical branching process with immigration in an independent and identically distributed random environment. Based on relations with a branching process (without immigration) in a random environment and using the associated random walk, we establish the Berry-Esseen bound in the central limit theorem and Cramer large deviation expansion for $\log Z_n$ under suitable moment conditions.

DISTRIBUTION DEPENDENT JUMP PROCESSES WITH RANDOM SWITCHING

Fubao XI *Beijing Institute of Technology, China*, E-mail: xifb@bit.edu.cn

Abstract: In this work we consider a class of distribution dependent jump processes with random switching, where the switching process may have a finite or a countably infinite state space. By virtue of the martingale approach, we first establish the existence and uniqueness theorem of the underlying processes for a special Markovian switching case. Using a martingale function, we then transfer the existence and uniqueness result onto the general state-dependent

switching case. In particular, we provide a typical example, the Schlögl model with random switching, which means that the reaction coefficients are random but not deterministic constants. Moreover, we also discuss the law of large numbers and the central limit theorem for the processes with mean field interactions.

TIME FRACTIONAL SPDE

Wei LIU *Jiangsu Normal University, China*, E-mail: weiliu@jsnu.edu.cn

Abstract: In this talk we present a method to solve (stochastic) evolution equations on Gelfand triples with general time-fractional derivative based on pseudo-monotonicity techniques. In particular, the strong dissipativity of generalized time-fractional derivatives on Gelfand triples of properly in time weighted L^2-path spaces is proved. As a consequence one obtains existence and uniqueness of solutions to semilinear and quasilinear evolution equations with generalized time-fractional derivatives.

This talk is mainly based on the joint works with Michael Röckner and José Luís da Silva.

LIMIT THEOREMS FOR CONTINUOUS-STATE BRANCHING PROCESSES WITH IMMIGRATION

Chunhua MA *Nankai University, China*, E-mail: mach@nankai.edu.cn

Abstract: A continuous-state branching process with immigration, whose branching mechanism is Ψ and immigration mechanism Φ, CBI(Ψ, Φ) for short, may have two different asymptotic regimes depending on whether $\int_0 \frac{\Phi(u)}{|\Psi(u)|}du < \infty$ or $\int_0 \frac{\Phi(u)}{|\Psi(u)|}du = \infty$. When $\int_0 \frac{\Phi(u)}{|\Psi(u)|}du < \infty$, CBIs either have a limit distribution or a growth rate dictated by the branching dynamics. When $\int_0 \frac{\Phi(u)}{|\Psi(u)|}du = \infty$, immigration overwhelms branching dynamics. Asymptotics in the latter case are studied via a non-linear time-dependent renormalization in law. Three regimes of weak convergence are exhibited. Processes with critical branching mechanisms subject to a regular variation assumption are studied. This talk is based on a joint work with Clement Foucart and Linglong Yuan.

STABILITY ANALYSIS OF STOCHASTIC DIFFERENTIAL EQUATIONS WITH SEMI-MARKOV SWITCHING

Quanxin ZHU *Hunan Normal University, China*, E-mail: zqx22@126.com

Abstract: Switched systems are composed of both continuous-time and discrete-time subsystems. Different from the traditional deterministic switched systems?and Markov switching systems, we are concerned with stochastic differential equations with semi-Markov switching. Firstly, we introduce the background of our concerning questions, and some existing results on this topic. Then, we present the definitions and properties of semi-Markov process, as well as the model of semi-Markov switched stochastic differential equations. Next, we present our main result on the stability of stochastic differential equations with semi-Markov switching, which

removes the previous strong condition: the transition rates are required to be uniformly bounded. Finally, we give an example to illustrate our result and make some comparisons with some known results on Markov switching systems.

EQUILIBRIA OF NONLINEAR DISTORTED BROWNIAN MOTIONS

Michael RÖCKNER *Bielefeld University, DE*, E-mail: roeckner@math.uni-bielefeld.de
Joint work with: Viorel Barbu (Romanian Academy, Iasi)

Abstract: This talk will review the connection of nonlinear Fokker–Planck–Kolmogorov (FPK) equations and McKean–Vlasov SDEs, with special emphasis on the case where the coefficients depend Nemytskii-type on the time marginal laws. A class of examples are nonlinear distorted Brownian motions. Recent results on their asymptotic behaviour, obtained through their corresponding nonlinear FPK equations, will be presented.

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ERGODICITY OF PERIODIC AND QUASI-PERIODIC MEASURES

Huaizhong ZHAO *Durham University, UK*, E-mail: huaizhong.zhao@durham.ac.uk

Abstract: In this talk, I will present main ideas of recent results on the ergodicity of random periodic processes and random quasi-periodic processes. I will explain periodic measures, quasi-periodic measures, lifting them on a cylinder to obtain an invariant measure and ergodicity. I will also touch some applications. This talk is based on a series of joint work with Chunrong Feng, Yu Liu, Yujia Liu, Baoyou Qu and Johnny Zhong.

ON BOUNDARY DECAY OF HARMONIC FUNCTIONS, GREEN KERNELS AND HEAT KERNELS FOR DOME NON-LOCAL OPERATORS

Zoran VONDRAČEK *University of Zagreb, CROATIA*, E-mail: vondra@math.hr

Abstract: In this talk, I will discuss non-local operators in open subsets of Euclidean space with critical potentials and kernels admitting a decay at the boundary. The focus will be on the boundary decay of non-negative harmonic functions, Green kernels, and heat kernels. I will explain how decay depends on the critical potential and the possible decay of the kernel at the boundary.

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BOUNDARY BEHAVIORS AT ∞ FOR FRAGMENTS IN SIMPLE EXCHANGEABLE FRAGMENTATION-COALESCENCE PROCESSES

Xiaowen ZHOU *Concordia University, Canada*, E-mail: xiaowen.zhou@concordia.ca

Abstract: We consider the exchangeable fragmentation-coagulation (EFC) processes, where the coagulations are multiple and not simultaneous, as in a Λ-coalescent, and the fragmentations dislocate at finite rate an individual block into sub-blocks of infinite size. Sufficient conditions are found for the block counting process to explode (i.e. to reach ∞) or not and for ∞ to be either an exit boundary or an entrance boundary. In a case of regularly varying fragmentation and coagulation mechanisms, we find regimes where the boundary ∞ can be either an exit, an entrance or a regular boundary.

This talk is based on joint work with Clement Foucart.

PHASE ANALYSIS OF A FAMILY OF STOCHASTIC REACTION-DIFFUSION EQUATIONS

Davar KHOSHNEVISAN *University of Utah, USA*, E-mail: davar@math.utah.edu

Abstract: We consider a reaction-diffusion equation of the type $\partial_t \psi = \partial_x^2 \psi + V(\psi) + \lambda\sigma(\psi)\dot{W}$ on $(0,\infty) \times \mathbf{T}$,subject to a " nice" initial value and periodic boundary, where $\mathbf{T} \cong [-1,1]$ and $\dot{W}$ denotes space-time white noise. The reaction term $V : \mathbf{R} \to \mathbf{R}$ belongs to a large family of functions that includes Fisher-KPP nonlinearities $[V(x) = x(1-x)]$ as well as Allen-Cahn potentials $[V(x)] = x(1-x)(1+x)$, the multiplicative nonlinearity $\sigma : \mathbf{R} \to \mathbf{R}$ is non random and Lipschitz continuous, and $\lambda > 0$ is a non-random number that measures the strength of the effect of the noise $\dot{W}$. The principal finding of this paper is that: (i) When λ is sufficiently large, the above equation has a unique invariant measures; and (ii) When λ is sufficiently small, the collection of all invariant measures is a non-trivial line segment, in particular infinite. This proves an earlier prediction of Zimmerman et al. (2000). Our methods also say a great deal about the structure of these invariant measures.

This is based on joint work with Kunwoo Kim (POSTECH), Carl Mueller (University of Rochester), and Shang-Yuan Shiu (National Central University).

SINGULAR KINETIC EQUATIONS AND APPLICATIONS

Xiangchan ZHU *Chinese Academy of Sciences, China*, E-mail:zhuxiangchan@126.com

Abstract: We study stochastic kinetic equations with singular coefficients, which are not well-defined in the classical sense and are understood by using the paracontrolled distribution method. We first develop paracontrolled calculus in the kinetic setting and use it to establish the global well-posedness for the singular stochastic linear kinetic equations. Moreover, based on the entropy method the global well-posedness for the nonlinear kinetic equations with singular kernels are also obtained. As applications we solve martingale problem for nonlinear kinetic distribution dependent stochastic differential equations with singular drifts.

SINGULAR INTEGRALS OF SUBORDINATORS AND APPLICATIONS TO SPDEs

Chang-Song DENG *Wuhan University*, E-mail: dengcs@whu.edu.cn

Abstract: I will talk about stochastic integrals driven by a general subordinator. We establish a zero-one law for the finiteness of the resulting integral as well as moment estimates. Applications to structural properties of SPDEs will be mentioned. Based on a joint work with R. Schilling (Dresden) and L. Xu (Macau).

EXPONENTIAL CONVERGENCE OF MEAN-FIELD INTERACTING PARTICLE SYSTEMS AND THE MCKEAN-VLASOV EQUATION

Liming WU *HIT, China and UCA, France*, E-mail: li-ming.wu@uca.fr

Abstract: We present the Poincaré and log-Sobolev inequality for mean-field interacting particle systems, uniform in number of particles. This is carried out by means of the results of Ledoux and of Zegarlinskii respectively, based on a priori estimate of the Lipschitzian norm of the Poisson operator of one single particle that I have got on 2009. The uniform log-Sobolev inequality will yield the exponential convergence in entropy of the McKean-Vlasov equation, generalizing the pioneer work of Carrillo-McCann-Villani in the convex case to non-convex case (double-well confinement potential). This talk is based on my joint work with A. Guillin, W. Liu and C.E. Zhang, accepted for publication by AAP.

REVISIT OF L.-K. HUA'S THEORY ON INPUT-OUTPUT MODELS

Yong-Hua MAO *Beijing Normal University, China*, E-mail: maoyh@bnu.edu.cn

Abstract: We revisit the Luo-Keng HUA's celebrating theory on the input-output models, which first discovered that the collapse time T_0 is finite. The collapse time T_M means the first time of some output product going to M or below. Actually, we prove the finiteness of the collapse time T_M for any $M \leq 0$. Via the strong ergodicity, we give the upper bound of T_M.

AVERAGING PRINCCIPLE FOR SLOW-FAST STOCHASTIC SYSTEM DRIVEN BY α-STABLE PROCESSES

Xiaobin SUN *Jiangsu Normal University, China*, E-mail: xbsun@jsnu.edu.cn

Abstract: In this talk, we will present some recent results about the averaging principle for slow-fast stochastic system driven by α-stable processes, where $\alpha \in (1, 2)$. More precisely, the strong and weak convergence orders are obtained for this kind of system in finite and infinite dimensions.

SDEs DRIVEN BY MULTIPLICATIVE LÉVY PROCESSES

Zhen-Qing CHEN *University of Washington, USA*, E-mail: zqchen@uw.edu

Abstract: In this talk, I will present results on weak as well as strong well-poshness results for solutions to time-inhomogeneous SDEs driven by stable-like Lévy processes with Hölder continuous coefficients. The Lévy measure of the Lévy process can be anisotropic and singular with respect to the Lebesgue measure on $\mathbb{R}^d$ and its support can be a proper subset of $\mathbb{R}^d$. Based on a joint work with Xicheng Zhang and Guohuan Zhao.

REGIME-SWITCHING JUMP-DIFFUSION PROCESSES WITH COUNTABLE REGIMES

Chao ZHU *University of Wisconsin-Milwaukee, USA*, E-mail: zhu@uwm.edu

Abstract: This work focuses on a class of regime-switching jump diffusion processes, which is a two component Markov processes $(X(t), \Lambda(t))$, where the analog component $X(t) \in R^d$ models the state of interest while the switching component $\Lambda(t) \in \{1, 2, \dots\}$ can be used to describe the structural changes of the state or random factors that are not represented by the usual jump diffusion formulation. Considering the corresponding stochastic differential equations, our main focus is on treating those with non-Lipschitz coefficients. We first show that there exists a unique strong solution to the corresponding stochastic differential equation. Then Feller and strong Feller properties and exponential ergodicity are investigated.

This is a joint work with Khwanchai Kunwai, Fubao Xi and George Yin.

QUENCHED AND AVERAGED TAILS OF THE HEAT KERNEL OF THE TWO-DIMENSIONAL UNIFORM SPANNING TREE

Martin T. BARLOW *University of British Columbia, Canada*
David A. CROYDON *Kyoto University, Japan*
Takashi KUMAGAI *Kyoto University, Japan*, E-mail: kumagai@kurims.kyoto-u.ac.jp

Key words: uniform spanning tree; random walk; heat kernel.

Mathematical Subject Classification: 60K37 (primary); 60D05; 60G57.

Abstract: We investigate the heat kernel of the simple random walk on the two-dimensional uniform spanning tree. We improve previous work [1] by demonstrating the occurrence of log-logarithmic fluctuations around the leading order polynomial behaviour for the on-diagonal part

of the quenched heat kernel. In addition we give two-sided estimates for the averaged heat kernel, and show that the exponents that appear in the off-diagonal parts of the quenched and averaged versions of the heat kernel differ. Finally, we derive various scaling limits for the heat kernel, the implications of which include enabling us to sharpen the known asymptotics regarding the on-diagonal part of the averaged heat kernel and the expected distance travelled by the associated simple random walk.

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SOME PROPERTIES OF A STATIONARY CONTINUOUS STATE BRANCHING PROCESS

Hui HE *Beijing Normal University, China*, E-mail: huihe@bnu.edu.cn

Abstract: We consider the genealogical tree of a stationary continuous state branching process with immigration. For a sub-critical stable branching mechanism, we consider the genealogical tree of the extant population at some fixed time and prove that, up to a deterministic time-change, it is distributed as a continuous-time Galton-Watson process with immigration. We also show that the sizes of the families of the extant population ranked according to their immigration time yields a Poisson-Kingman distribution. And a natural link to the Bolthausen-Sznitman coalescent is also obtained. The talk is based on a joint work with R. Abraham and J.-F. Delmas.

INDEFINITE BACKWARD STOCHASTIC LINEAR-QUADRATIC OPTIMAL CONTROL PROBLEMS

Jie XIONG *Southern University of Science and Technology, China*, E-mail: xiong79@yahoo.com

Abstract: This talk is concerned with a backward stochastic linear-quadratic (LQ, for short) optimal control problem with deterministic coefficients. The weighting matrices are allowed to be indefinite, and cross-product terms in the control and state processes are present in the cost functional. Based on a Hilbert space method, necessary and sufficient conditions are derived for the solvability of the problem, and a general approach for constructing optimal controls is developed. The crucial step in this construction is to establish the solvability of a Riccati-type equation, which is accomplished under a fairly weak condition by investigating the connection with forward stochastic LQ optimal control problems. This talk is based on a joint paper with Sun and Wu.

A NOTE ON THE ASYMPTOTIC BEHAVIOR OF THE HEIGHT FOR A BIRTH-AND-DEATH PROCESS

Xianyuan WU *Capital Normal University, China*, E-mail: wuxy@cnu.edu.cn

(Joint work with **Feng WANG, Rui ZHU**)

Abstract: This talk focuses on the asymptotic behavior of the *height* of birth-and-death process with finite states. First of all, a weak Law of Large Number is obtained; Secondly, based on accurate estimations on the asymptotic mean and variance, a limit theorem for the distribution of the normalized height is obtained (converging to a degenerate distribution).

LARGE N LIMIT OF THE $O(N)$ LINEAR SIGMA MODEL VIA STOCHASTIC QUANTIZATION

Rongchan ZHU *Beijing Institute of Technology, China*, E-mail: zhurongchan@126.com

Abstract: In this talk we discuss large N limits of a coupled system of N interacting Φ^4 equations posed over $\mathbb{T}^d$ for $d = 1, 2, 3$, known as the $O(N)$ linear sigma model. Uniform in N bounds on the dynamics are established, allowing us to show convergence to a mean-field singular SPDE, also proved to be globally well-posed. Moreover, we show tightness of the invariant measures in the large N limit.

For large enough mass, they converge to the (massive) Gaussian free field, the unique invariant measure of the mean-field dynamics, at a rate of order $1/\sqrt{N}$ with respect to the Wasserstein distance. We also consider fluctuations and obtain tightness results for certain $O(N)$ invariant observables, along with an exact description of the limiting correlations in $d = 1, 2$. This talk is based on joint work with Hao Shen, Scott Smith and Xiangchan Zhu.

SCALING LIMITS OF DIRECTED POLYMERS IN SPATIAL-CORRELATED ENVIRONMENT

Fuqing GAO *Wuhan University, China*, E-mail: fqgao@whu.edu.cn
(Joint work with **Yingxia CHEN**)

Abstract: We consider a directed polymer model in dimension $1 + 1$, where the random walk is attracted to stable law and the environment is time-independent and space-correlated. We show that the scaled partition function of directed polymers in the intermediate disorder regime converges to the solution of some stochastic heat equations driven by time-white spatial-colored noise.

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SOME LIMIT THEOREMS ASSOCIATED WITH INTEGRAL FUNCTIONALS OF fBM

Litan YAN *Donghua University, China*, E-mail: litanyan@dhu.edu.cn

Abstract: In this talk, we obtain some limit theorems associated with integral functionals

$$\int_0^t f(s, B_s^H)ds,$$

where f is a Borel function and B^H is a fractional Brownian motion with Hurst index $H \in (0, 1)$.

LIMIT THEOREMS FOR MULTISCALE STOCHASTIC DYNAMICAL SYSTEMS

Longjie XIE *Jiangsu Normal University, China*, E-mail: longjiexie@jsnu.edu.cn

Abstract: We study the asymptotic behavior for an inhomogeneous multiscale stochastic dynamical system with singular coefficients. Depending on the averaging regime and the homogenization regime, two strong convergences in the averaging principle of functional law of large numbers type are established. Then we consider the small fluctuations of the system around its average. Nine cases of functional central limit type theorems are obtained. In particular, even though the averaged equation for the original system is the same, the corresponding homogenization limit for the normal deviation can be quite different due to the difference in the interactions between the fast scales and the deviation scales. We provide quite intuitive explanations for each case. Furthermore, sharp rates both for the strong convergences and the functional central limit theorems are obtained, and these convergences are shown to rely only on the regularity of the coefficients of the system with respect to the slow variable, and do not depend on their regularity with respect to the fast variable, which coincide with the intuition since in the limit equations the fast component has been totally averaged or homogenized out.

ON THE MULTI-BUBBLE BLOW-UP SOLUTIONS TO STOCHASTIC NONLINEAR SCHRÖDINGER EQUATIONS

Deng ZHANG *Shanghai Jiao Tong University, China*, E-mail: dzhang@sjtu.edu.cn

Abstract:In this talk, we are mainly concerned with the multi-bubble blow-up solutions to focusing mass-critical stochastic nonlinear Schrödinger equations, in the controlled rough path sense. In both dimensions one and two, we construct the multi-bubble blow-up solutions, which concentrate at finite distinct points and behave as a sum of pseudo-conformal blow-up solutions near the blow-up points. The upper bound of asymptotic behavior is closely related to the

flatness of noise at the blow-up points. Moreover, the conditional uniqueness is proved for multi-bubble solutions in the energy class with the asymptotic behavior of order $(T-t)^{3+}$. Similar results are also obtained for nonlinear Schrödinger equations with lower order perturbations, in the absence of the classical pseudo-conformal symmetry and the conservation law of energy. This talk is based on the joint work with Yiming Su.

BROWNIAN MOTION AND NS EQUATIONS rownian motion and NS equations

Shizan FANG *University of Burgundy, France*, E-mail: fang@u-bourgogne.fr

Abstract:Consider the Navier-Stokes equation on $\mathbf{R}^3$:

$$\partial_t u_t + (u_t \cdot \nabla)u_t - \nu\triangle u_t + \nabla\rho_t = 0, \quad \nabla \cdot u_t = 0, \quad u|_{t=0} = u_0,$$

where u_t is the velocity of an incompressible viscous uid with kinematic viscosity $\nu > 0$. The vorticity ξ_t is a vector field defined by $\xi_t = \nabla \times u_t$. In dimension 2, u_t and ξ_t are orthogonal, but in dimension 3, the term $u_t \cdot \xi_t$ is called **helicity** and to be handled. The vorticity satisfies the equation:

$$\frac{\partial \xi_t}{\partial t} + \nabla_{u_t}\xi_t - \nu\triangle\xi_t = \nabla^s_{\xi_t} u_t$$

where $\nabla^s u_t$ is the symmetric part of ∇u_t, called the **strain tensor**, also to be handled.

Theorem. The term

$$\widehat{Ric}^t(\xi_t)\cdot\xi_t = \frac{1}{2\nu^2}(u_t\cdot\xi_t)^2 - \frac{1}{\nu}\nabla^s_{\xi_t}u_t\cdot\xi_t$$

is the Ricci tensor associated to the Ikeda-Watanabe connection while rolling a flat Brownian motion on manifolds.

This talk is based on a joint work with Zhongmin QIAN.

A KESTEN-STIGUM TYPE THEOREM FOR A SUPER-CRITICAL MULTI-TYPE BRANCHING PROCESS IN A RANDOM ENVIRONMENT

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Abstract: We consider a branching process with a random environment, in which the reproduction law of generation n depends on the random environment at time n, unlike a constant distribution assumed in the Galton-Watson process. The famous Kesten-Stigum theorem on a supercritical multi-type Galton-Watson process gives a precise description of the exponential increasing rate of the population size via a criterion for the non-degeneracy of the fundamental branching martingale. Finding the corresponding result in the random environment case is a longstanding problem. For the single-type case the problem has been solved by Athreya and Kaplin (1971) and Tanny (1988), but for the multi-type case the problem has been open for about 50 years. In this talk we present a recent work in which we solve this problem in the typical case, by constructing a suitable martingale which reduces to the fundamental branching martingale in the constat environment case, and by establishing a criterion for the non-degeneracy of its

limit. This work open ways in establishing other limit theorems, such as law of large numbers, central limit theorems, Berry-Essen bound, and large deviation results.

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NUMBER OF BIRTHS ON THE NEGATIVE HALF-LINE IN BINARY BBM

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Abstract: We consider a binary branching Brownian motion on the real line and we add a critical drift to the motions so that it is in the boundary case. It is known that in this system, the cloud of particles moves eventually to $+\infty$. We study the total number of particles born on the negative half-line, especially its tail decay.

LARGE-SCALE AND LARGE-TIME BEHAVIOUR OF MEAN-FIELD INTERACTING PARTICLE SYSTEMS ON BLOCK-STRUCTURED NETWORKS

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Abstract: Since Kac's and McKean's seminal work, the mean-field theory has been widely exploited to study the time evolution of large stochastic interacting particle systems. In the classical homogeneous setting with a complete interaction graph, the big picture is well understood, and various asymptotic results have been established. Though such assumptions are reasonable in statistical physics, it might no longer be the case when considering other applications, such as telecommunication networks. Therefore, it is of interest to study systems, for which the homogeneity and/or the complete interaction assumptions are no longer relevant.

In this talk, we take one direction towards heterogeneity by considering systems in a multi-population paradigm. Namely, we present a model for block-structured networks with dynamically changing multi-color nodes, in which the interactions are described through local empirical measures (instead of a global empirical measure for the classical setting). Two levels of heterogeneity are considered: between and within the blocks, respectively. We study both large-scale and large-time asymptotics of the system. We first present, under original regularity conditions, several limiting results in $N \to \infty$ asymptotics, such as propagation of chaos, laws of large numbers, and large deviation principles for the vectors of empirical measures and the empirical processes together with the LDP of the corresponding unique invariant measure. We then see how to exploit the latter results to investigate the large-time behavior of the empirical process vector by relying on the Freidlin-Wentzell theory and the work of Hwang and Sheu. In particular, we present some metastable phenomena arising at large N and large t when the limiting McKean-Vlasov system contains multiple ω-limit sets.

This talk is based on the joint work with Don Dawson and Ahmed Sid-Ali.

PERIODIC SOLUTIONS OF HYBRID JUMP DIFFUSION PROCESSES

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Abstract: We investigate periodic solutions of regime-switching jump diffusions. Uniqueness of periodic solutions to the corresponding SDEs or SPDEs is obtained by the strong Feller property and irreducibility of the associated time-inhomogeneous semigroups. Concrete examples are presented to illustrate the results. This talk is based on joint work with Xiao-Xia Guo and Chun Ho Lau.

THE EXISTENCE OF QUASI-INVARIANCE FLOW ON LOOP SPACE OVER A NON-COMPACT RIEMANNIAN MANIFOLD

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Abstract: Based on the first and second order gradient estimates for logarithmic heat kernel obtained recently, we will prove the existence of quasi-invariance flow on loop space over a Riemannian manifold which is only complete and stochastically complete. This talk is based on a ongoing work with Xue-Mei Li and Bo Wu.

STRONG CONVERGENCE AND ASYMPTOTIC EXPONENTIAL STABILITY OF MODIFIED TRUNCATED EM METHOD FOR NEUTRAL STOCHASTIC DIFFERENTIAL EQUATIONS WITH TIME-DEPENDENT DELAY

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Abstract:We consider asymptotic exponential stability of the exact solution and the corresponding modified truncated EM (MTEM) method for neutral stochastic differential equations (NSDEs) with time-dependent delay. We obtain sufficient conditions under which the MTEM method replicate the exponential stability of the exact solution no matter time-dependent delay $\delta(t)$ is bounded or not. To make sure that the stability conclusions are meaningful, we with first obtain the strong convergence of the MTEM method. Two examples are presented to illustrate our conclusions.

CONSTRAINED PDMDPs ON FINITE HORIZON

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Abstract: In this talk we consider a multi-constrained problem for piecewise deterministic Markov decision processes (PDMDPs) with unbounded cost and transition rates. The goal is to minimize one type of expected finite-horizon cost over history-dependent policies while keeping some other types of expected finite-horizon costs lower than some tolerable bounds. Using the Dynkin's formula for the PDMDPs, we obtain an equivalent characterization of occupancy measures, and express the expected finite-horizon costs in terms of occupancy measures. Then, we give suitable conditions, under which the existence of a constrained-optimal policy is established, the linear programming formulation and its dual program for the constrained problem are derived, and the strong duality between the two programs is given. Finally, we give an example for demonstrating our results.

QUASI-STATIONARY DISTRIBUTIONS FOR MARKOV CHAINS

Hanjun ZHANG *Xiangtan University, China*, E-mail: hjz001@xtu.edu.cn

Abstract: The paper of talk extends and clarified results of Ferrari et al.(1995), which finds conditions for the existence of a quasi-stionary distribution(QSD) for continuous-time Markov chains.The talk also deals with the existence, uniqueness and domains of attraction of QSDs for stochastically monotone Markov chains.

GREEN FUNCTION ESTIMATES FOR SECOND ORDER ELLIPTIC OPERATOR IN NON-DIVERGENCE FORM

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Abstract: Two-sided sharp Green function estimates are obtained for second order uniformly elliptic operators in non-divergence form with Dini continuous coefficients in bounded $C^{1,1}$ domains, which are shown to be comparable to that of the Dirichlet Laplace operator in the domain. The first and second derivative estimates of the Green functions are also derived. This talk is based on a joint work with Professor Zhen-Qing Chen.

GLOBAL WELL-POSEDNESS OF STOCHASTIC REACTION-DIFFUSION EQUATIONS ON THE WHOLE REAL LINE WITH LOGARITHMIC NONLINEARITY DRIVEN BY SPACE-TIME WHITE NOISE

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Abstract: We are concerned with the well-posedness of stochastic reaction-diffusion equations on the whole real line with logarithmic nonlinearity driven by space-time white noise. The essential obstacle is caused by the explosion of the supremum norm of the solution, making the usual truncation procedure invalid. In this paper, we prove that there exists a unique global solution to the stochastic reaction-diffusion equation. Because of the nature of the nonlinearity, to get the uniqueness, we are forced to work with the first order moment of the solutions on the space $C_{tem}(\underline{\mathrm{R}})$ with a specially designed norm. Our approach depends heavily on the new,

precise lower order moment estimates of the stochastic convolution and a new type of Gronwall's inequalities we obtained, which are of interest on their own right.

OBSERVABILITY PROBLEM FOR SOME STOCHASTIC PARTIAL DIFFERENTIAL EQUATIONS

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Abstract:Observability problem is one of the fundamental problems in control theory. On the other hand, it relates to the unique continuation problem for the equations which describe the control systems. In this talk, we survey some recent progress on the observability problem for control systems governed by some typical stochastic partial differential equations.

GALTON-WATSON BRANCHING PROCESSES WITH COUNTABLY MANY TYPES AND INFINITE SECOND MOMENTS

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Key words: branching processes, infinitely many types, survival probability, Yaglom-type limit theorem

Mathematical Subject Classification: 60J80

Abstract: We consider an indecomposable Galton-Watson branching process with countably infinitely many types. Assuming that the process is critical and allowing for infinite variance of the offspring sizes of some (or all) types of particles we describe the asymptotic behavior of the survival probability of the process and establish a Yaglom-type conditional limit theorem for the infinite-dimensional vector of the number of particles of all types.

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NONZERO-SUM EXPECTED AVERAGE DISCRETE-TIME STOCHASTIC GAMES

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Abstract: We study nonzero-sum discrete-time stochastic games with an uncountable state space and Borel action spaces under the expected average payoff criterion. The reward functions can be possibly unbounded and the transition law is a convex combination of finitely many probability measures dependent on the state variable and dominated by some probability measure on the state space. We introduce several auxiliary static game models and obtain their properties. Moreover, by a technique of extending the space state, we introduce auxiliary stochastic game models and derive the uniform geometric ergodicity of Markov chains taking values in the extended state space. Furthermore, we show the existence of a stationary almost Markov Nash equilibrium via an approximation method. This is a joint work with Qingda Wei.

WASSERSTEIN LIMIT FOR EMPIRICAL MEASURES MEASURES OF DIFFUSION PROCESSES

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Abstract: The limit in Wasserstein distance is presented by using eigenvalues and eigenfunctions for the empirical measures of diffusion processes on compact Riemannian manifolds without boundary or with reflecting/killing boundary. The convergence rate is estimated also for SDEs and semilinear SPDEs.

HEAT KERNEL UPPER BOUNDS FOR SYMMETRIC MARKOV PROCESSES

Jian WANG *Fujian Normal University, China*, E-mail: jianwang@fjnu.edu.cn

Abstract: In this talk, we show that under some mild assumptions Nash-type inequalities only can yield off-diagonal heat kernel upper bounds for symmetric Markov processes. This extends the famous work by Carlen-Kusuoka-Stroock. We also show a new and direct approach to obtain large time heat kernel estimates for symmetric strongly local Dirichlet forms under general volume doubling setting.

THE DOWN/UP CROSSING PROPERTIES OF MARKOV BRANCHING PROCESSES

Junping LI *Central South University, China*, E-mail: jpli@mail.csu.edu.cn

Abstract: It is well-known that 0 is the absorbing state for a branching system. Each particle in the system lives a random long time and gives a random number of new particles at its death time. It stops when the system has no particle. This paper is devoted to studying the fixed range crossing numbers until any time t. The joint probability distribution of fixed range crossing numbers of such processes until time t is obtained by using a new method. In particular, the probability distribution of total death number is given for Markov branching processes until time t.

Abstracts(posters) 墙报摘要

A Wiener-Hopf factorization related potential measure for diffusion processes

Man CHEN *Capital Normal University, China*, E-mail: chenman1119@icloud.com

Abstract: For time-homogeneous diffusion processes, we adopt the approximate method to find expressions, in terms of solutions to the associated diffusion equations with the diffusions generator, for a potential measure involving the maximum (minimum) and the last time of reaching the maximum (minimum) up to time t before exit the interval (a, b), and also the joint Laplace transform for the Wiener-Hopf factorization for time-homogeneous diffusion processes. As applications, we obtain more explicit expressions on the joint Laplace transforms related the potential measure for Brownian motion with drift and Brownian motion with alternating drift. This is a joint work with Yechen and Xianyuan Wu.

Lower deviation probability for the maximum of a branching random walk

Zengcai CHEN *Beijing Normal University, China*, E-mail: @mail.csu.edu.cn

Abstract: Given a supercritical branching random walk, considerting its maximal position, Gantert and Höfelsauer (2018) and Chen and He (2020) obtained the first order of the decay for the deviation probabilities. In this work, we get a preciser result for the decay of the lower deviation probability, i.e. $\mathbb{P}(M_n \leq \alpha x^* n)$ for $\alpha < 1$ in Schröder case.

The probabilistic solution of a system of semilinear elliptic PDEs under the third boundary conditions

Junxia DUAN *Central South University, China*, E-mail: lulinxiaguang@csu.edu.cn

Abstract: In this paper, we establish existence and uniqueness of weak (Sobolev) solution to the third boundary value problem for a class of semilinear elliptic partial differential equations with singular coefficients. Our method is probabilistic. The gauge theory and backward stochastic differential equations with singular coefficients play an important role in our approach.

On asymptotic finite-time ruin probabilities of a new bidimensional risk model with constant interest force and dependent claims

Bingzhen GENG *Central South University, China*, E-mail: gengbingzhen1@163.com

Abstract: Consider a new continuous-time bidimensional renewal risk model with constant force of interest, in which every kind of business is assumed to pay two classes of claims called the first and second ones, respectively. Suppose that the first class of claim vectors form a sequence of independent and identically distributed random vectors following a general dependence structure which share a common renewal counting process, and the second class of claim vectors, independent of the first class of claim vectors, constitute another sequence of independent and identically distributed random vectors which arrive according to two different renewal counting process. For such a model, when the claims are assumed to be subexponential or belong to the intersection of long-tailed and dominatedly varying-tailed class, some asymptotic formulas on finite-time ruin probabilities are derived. The obtained results substantially extend some existing ones in the literature.

Quasi-stationary behavior for Markov-modulated Markov chains

Wendi LI *Central South University, China*, E-mail: liwendi@csu.edu.cn

Abstract: In this talk, we show the quasi-stationary distribution for Markov-modulated Markov chains. We focus on two fundamental aspects (existence and uniqueness, domain of attraction) in connection with quasi-stationary distribution. We first provide a sufficient criterion for the existence of the quasi-stationary distribution. An iterative algorithm to compute all quasi-stationary distributions is presented. We then carry out a study on the domain of attraction for the quasi-stationary distribution under a uniqueness condition. In addition, we apply the results to M/G/1-type Markov chains, and characterize the asymptotic behavior of the quasi-stationary distribution for this model. Finally, a scalar example is given to illustrate these results.

Conditional L^1-convergence for the martingale of a critical branching process in random environment

Shengli LIANG *Beijing Normal University, China*, E-mail: liangshengli@mail.bnu.edu.cn

Abstract: Consider a critical branching process (Z_n) in random environment (ξ_n), a sufficient condition is given for the corresponding martingale $\frac{Z_n}{e^{S_n}}$ to converge in L^1 or to degenerate under $\mathbb{P}^+$, the probability under which the associated random walk conditioned to stay nonnegative.

A scaling limit theorem for Galton-Watson in varying environments

Jiawei LIU *Beijing Normal University, China*, E-mail: jwliu@mail.bnu.edu.cn

Abstract: We prove a scaling limit theorem for discrete Galton-Watson processes in varying environments. A simple sufficient condition for the weak convergence in the Skorokhod space is given in terms of probability generating functions. The limit theorem gives rise to the continuous-state branching processes in varying environments studied recently by several authors.

Extinguishing Behaviors for Continuous-State Nonlinear Branching Processes

Yingchun TANG *Central South University, China*, E-mail: 1060864320@qq.com

Abstract: A nonnegative continuous-state branching process becomes extinguishing if it converges to 0 but never hits 0 as time goes to infinity. We consider a class of continuous-state nonlinear processes obtained from spectrally positive stable like Levy processes by Lamperti type time changes using regularly varying (at 0) rate functions, and obtain several large time asymptotic results on the extinguishing behaviors. In particular, we show that, depending on whether the stable index for the spectrally positive Lévy process is smaller than or equal to the regularly varying index for the rate function, a phase transition occurs for the convergence of rescaled first passage times of levels approaching 0. We find conditions on convergence in probability and convergence almost surely, respectively. We also obtain integral tests on almost sure long time fluctuation of the running minimum process.

Exponential and strong ergodicity for time-changed symmetric stable processes

Tao WANG *Beijing Normal University, China*, E-mail: wang_tao@mail.bnu.edu.cn

Abstract: We obtain explicit criteria for exponential ergodicity and strong ergodicity for one-dimensional time-changed symmetric α-stable processes with $\alpha \in (1, 2)$. Explicit lower bounds for ergodic convergence rates are also given.

Two-time-scale Regime-Switching Stochastic Kolmogorov Systems with Wideband Noises

Zhexin WEN *Central South University, China*, E-mail: zhexinwen@gmail.com

Abstract: In our recent work, in lieu of using white noise, we examined Kolmogorov systems driven by wideband noise. Such systems naturally arise in statistical physics, biological and ecological systems, and many related fields. One of the motivations of our study is to treat more realistic models than the usually assumed stochastic differential equation models. The rationale is that a Brownian motion is an idealization used in a wide range of models, whereas wideband noise processes are much easier to be realized in the actual applications. This paper further investigates the case that in addition to the wideband noise process, there is a singularly perturbed Markov chain. The added Markov chain is used to model discrete events. Although it is a more realistic formulation, because of the non-Markovian formulation due to the wideband noise and the singularly perturbed Markov chain, the analysis is more difficult. Using weak convergence methods, we obtain a limit result. Then we provide several examples for the utility of our findings.

Optimal cost mechanisms in queues

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Abstract: In this paper, we propose a queueing-game-theoretic model and analyze the customer strategic behavior and social optimization in both observable and unobservable M/G/1 queues with impatience, where arriving customers decide whether to join the system or balk based on a new binary and random reward-cost structure and two different cost mechanisms. Our main results are as follows. First, we derive closed-form solutions for the equilibrium strategies, optimal strategies and social welfare in two cases. Second, extensive numerical experiments are carried out to illustrate our theoretic results and the impact of impatience on equilibrium strategies, optimal strategies and social welfare. Finally, we compare the effect of impatience on social welfare in observable queues and unobservable queues, we find that, in observable queues, disclosing information to the customers that raises more social welfare. Another important conclusion is that PBS case is a better cost mechanism to improve the social welfare by regulating the behaviors of strategic customers. Our findings have several implications for queue management in many service settings, such as hotlines, call centers and so on.

A Law of Large Numbers for the absorbed mass of super Brownian motion with immigration

Yaping ZHU *Beijing Normal University, China*, E-mail: zhuyp@mail.bnu.edu.cn

Abstract: We prove a Law of Large Numbers for the absorbed mass of critical super Brownian motion with immigration , which leads to a constant determined by the immigration measure and the position of the barrier.

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第 16 届“马氏过程及相关论题国际学术研讨会”疫情防控工作方案

湖南长沙为疫情低风险地区，为了会议的顺利组织和召开，保障参会人员及工作人员身体健康，根据防疫政策要求，制定如下疫情防控工作方案。

一、会场准备

会前对会场严格做好通风消毒工作，并配备相关疫情防控物资（口罩、消毒液、洗手液等）。

二、会议期间防控措施

（一）健康监测

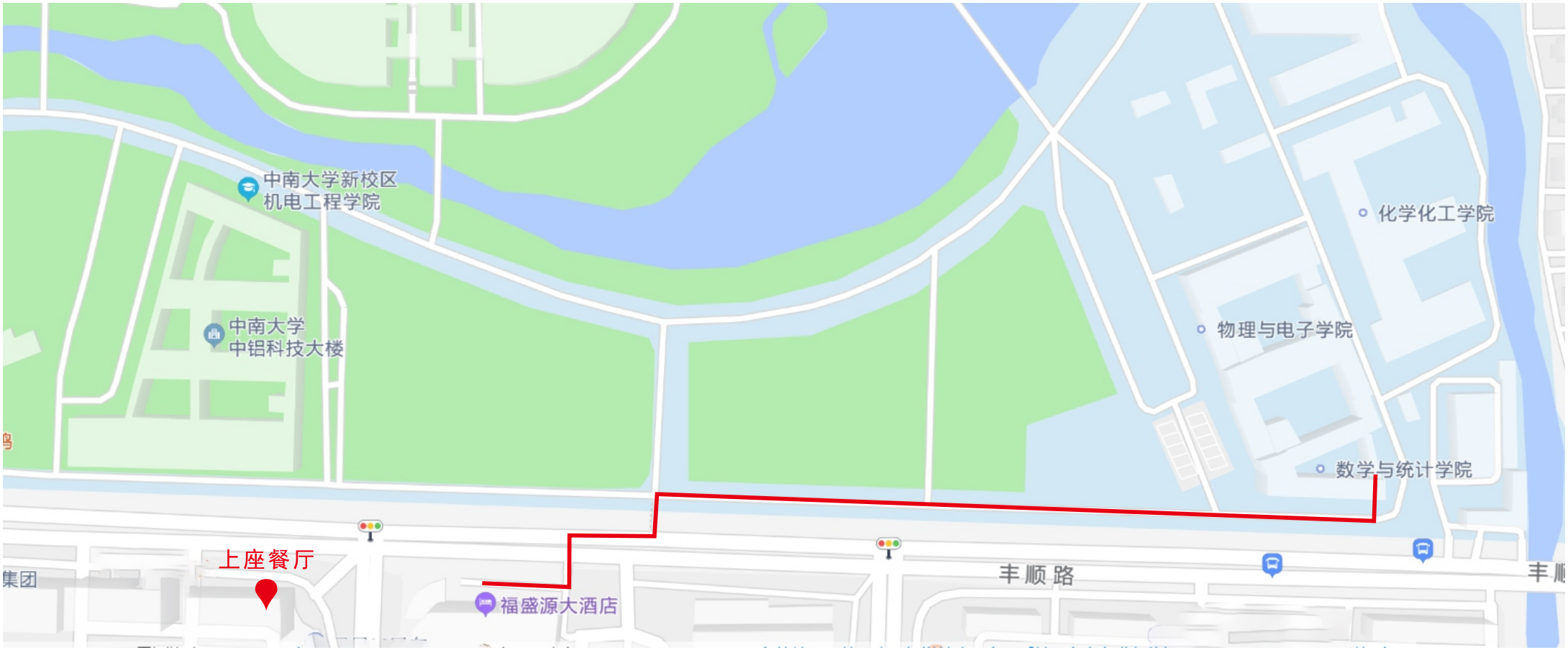
参会专家在会议期间配合会务组测体温，佩戴口罩。体温正常且持健康绿码的方可参会。

（二）通风和消毒

加强会场的日常通风消毒，尤其是会场、电梯间、电梯按钮、卫生间、公共休息区等重点部位的消毒工作。

三、应急防疫处置

如在会场发现健康异常人员，迅速转送至临时隔离场所，立即报告长沙疾控中心，并开展疫情处置工作。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中南大学
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化学化工学院
物理与电子学院
数学与统计学院
上座餐厅
福盛源大酒店
丰顺路

实验室简介

分析数学及其应用湖南省重点实验室依托于中南大学数学双一流建设学科，2020年12月经湖南省科技厅正式批准成立。中南大学是教育部直属重点大学、国家“211工程”首批重点建设高校、国家“985工程”部省重点共建高水平大学和国家“2011计划”首批牵头高校，2017年9月入选世界一流大学A类建设高校。同时，中南大学数学学科是教育部认定的国家一流建设学科。目前数学学科已经形成了多个有特色、有优势的学科研究方向和创新能力强、结构合理的学术队伍，在一些国际前沿的研究领域取得了具有影响的科研成果。现任实验室主任由中南大学焦勇教授担任，学术委员会主任由中国科学院周向宇院士担任。

分析数学及其应用湖南省重点实验室是以分析学为主题，辐射数学的相关研究领域。实验室将集聚一批以分析数学为主的高端人才，在长期持续的科研活动中解决理论与应用问题，建立起一个稳定的梯队合理的科研团队，造就一批具有前瞻性和国际视野的高端创新人才群体。本实验室作为分析数学理论及其应用的高端平台和交叉创新人才的重要聚集地，将充分发挥平台优势和人才资源优势，紧紧围绕泛函分析及其应用、马氏过程及其应用、微分方程及其应用、数值分析及其应用等开展分析数学及其应用交叉学科研究，发挥中心各方向的研究优势，加强分析数学在科技创新的重要作用，引领湖南科技创新水平，助力国家和湖南社会经济展。

分析数学及其应用湖南省重点实验室致力于搭建数学与其它学科交叉合作的高水平研究平台，凝聚湖南省以及国内外数学及相关学科力量，协同攻关，推动跨学科交叉创新，解决其中的关键科学问题，打造一支高水平的数学与应用数学人才队伍。争取在2025年左右，分析数学及其应用湖南省重点实验室若干研究方向科研水平跻身国际先进水平，并建成国内具有重要影响力的研究中心与人才培养基地。

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