Perspectives and Prospects

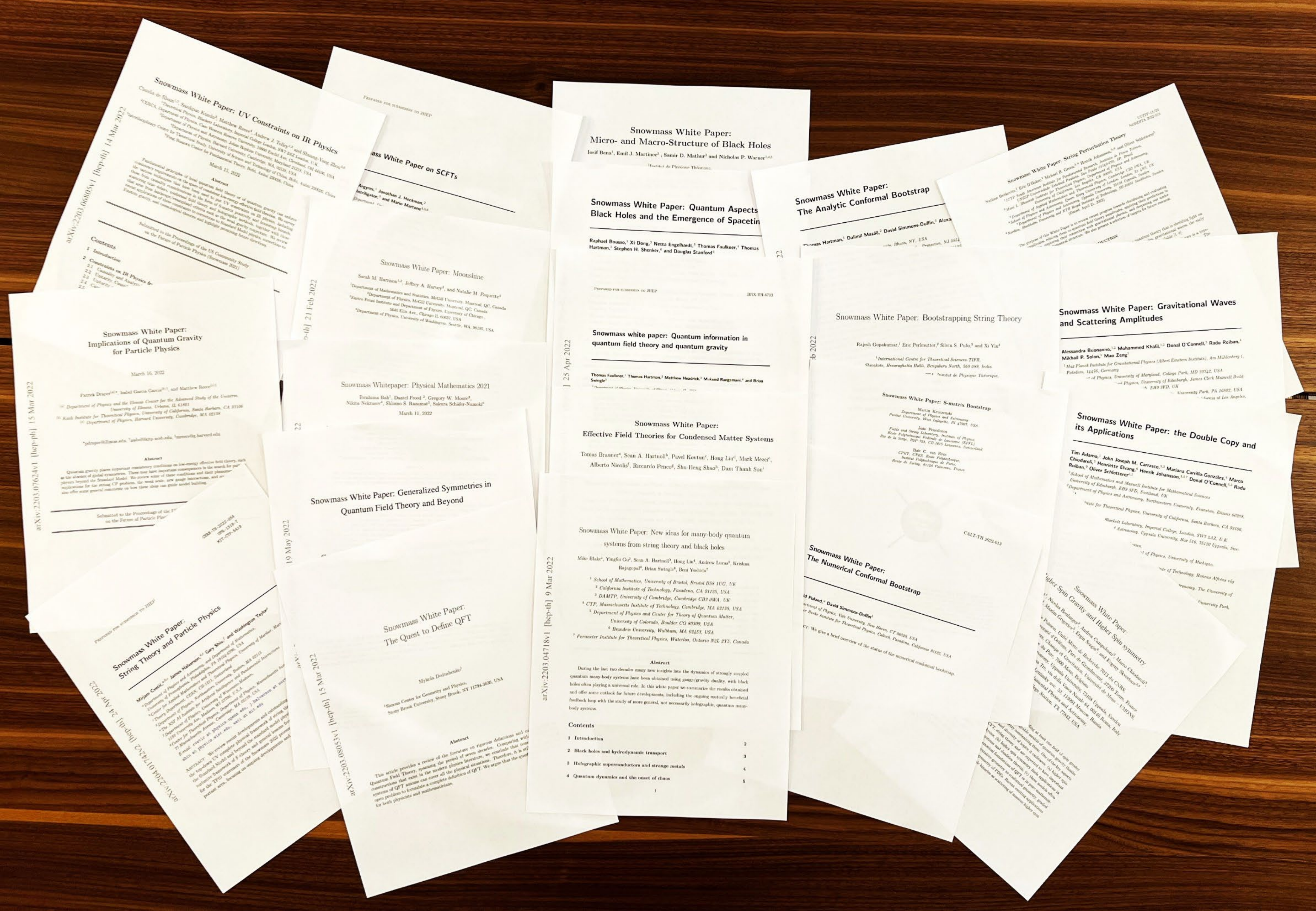
Hirosi Ooguri

Strings 2022

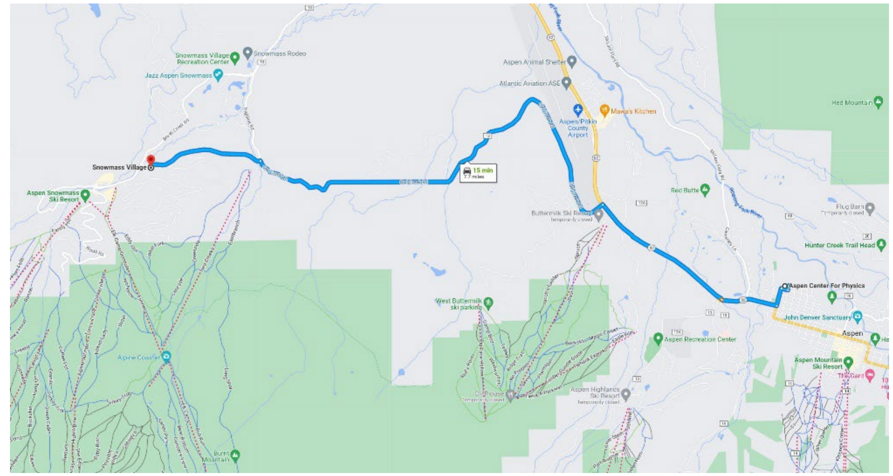
18 – 22 July

The original title of the session was **Views and Visions**, but Rajesh and I thought discussing those would be above our paygrades and asked the organizers to tone it down to **Perspectives and Prospects**.

In fact, there have been plenty of **Views and Visions** on string theory posted on the arXiv over the past six months.


Snowmass White Paper: UV Constraints on IR Physics
Snowmass White Paper: Micro- and Macro-Structure of Black Holes
Snowmass White Paper: The Analytic Conformal Bootstrap
Snowmass White Paper: String Perturbation Theory
Snowmass White Paper: Moonshine
Snowmass White Paper: Implications of Quantum Gravity for Particle Physics
Snowmass Whitepaper: Physical Mathematics 2021
Snowmass white paper: Quantum information in quantum field theory and quantum gravity
Snowmass White Paper: Bootstrapping String Theory
Snowmass White Paper: Gravitational Waves and Scattering Amplitudes
Snowmass White Paper: S-matrix Bootstrap
Snowmass White Paper: Effective Field Theories for Condensed Matter Systems
Snowmass White Paper: the Double Copy and its Applications
Snowmass White Paper: Generalized Symmetries in Quantum Field Theory and Beyond
Snowmass White Paper: New ideas for many-body quantum systems from string theory and black holes
Snowmass White Paper: The Numerical Conformal Bootstrap
Snowmass White Paper: Higher Spin Gravity and Higher Spin Symmetry
Snowmass White Paper: String Theory and Particle Physics
Snowmass White Paper: The Quest to Define QFT

Snowmass



"Snowmass will define the most important questions for the field of particle physics and identify promising opportunities to address them."

American Physical Society,
Division of Particle Physics Community Planning Exercise

Rather than giving an overview of the field by going through these Snowmass white papers, I would like to make a few remarks from my idiosyncratic perspective.

$$S = \frac{\text{Area}}{4G}$$

“The law that entropy always increases – the second law of thermodynamics – holds, I think, the supreme position among the laws of Nature. If someone points out to you that your pet theory of the universe is in disagreement with Maxwell’s equations – then so much the worse for Maxwell’s equations. If it is found to be contradicted by observations – well, these experimentalists do bungle things sometimes. But **if your theory is found to be against the second law of thermodynamics I can give you no hope**; there is nothing for it but to collapse in deepest humiliation.”

Gifford Lectures delivered by Arthur Eddington
University of Edinburgh, January – March 1927

tram line 71 to Zentralfriedhof

Gruppe 14 C, #1

$$S = \frac{\text{Area}}{4G}$$

The **black hole entropy formula** has inspired significant progress in string theory and quantum gravity.

Its derivation by Strominger and Vafa gave us deep insight into microstates of black holes and led developments of powerful new techniques.

$$S = \frac{\text{Area}}{4G} + S_{\text{bulk}}$$

"better defined than either term on the right hand side"

The 2019 resolution of the puzzle about the von Neumann entropy of Hawking radiation demonstrated the power of the quantum extremal surface formula.

It was a semi-classical calculation, analogous to the **Gibbons-Hawking calculation** of the black hole entropy.

Analogous to the **Strominger-Vafa calculation** would be to realize the recent proposal by Akers, *et al.* in a theory related to the Einstein gravity.

Wormholes play an important role in these and other recent developments such as the study of **quantum chaos**.

Are the phenomena low dimensional artifacts or are they suggesting general features of non-perturbative gravity?

The recent paper by Schlenker and Witten sharpens the puzzle on their role in **ensemble averaging**.

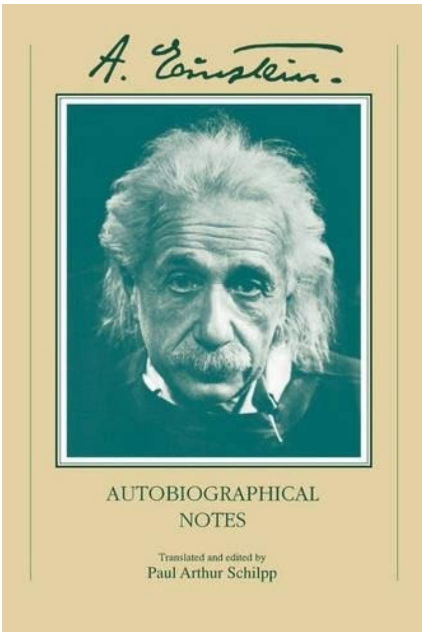
To address the questions on wormholes,

- No Global Symmetry — Wheeler (1957), …
- Distance Conjecture — Vafa, H.O. (2007)
- Cobordism Conjecture — McNamara, Vafa (2019)

may be relevant.

They are closely related to each other,
and they seem to be common features
of all known quantum gravity theories.

An earlier formulation:



Autobiographical Notes
by Albert Einstein

After explaining the notion of the natural units,

“…, then **only dimensionless constants could occur in the basic equations of physics**. Concerning such I would like to state a theorem which at present cannot be based upon anything more than upon a faith in the simplicity, *i.e.*, intelligibility, of nature: **there are no arbitrary constants of this kind** …”

A modern formulation:

Every parameter in quantum gravity is an expectation value of a **dynamical field** and can be varied by changing its expectation value.

Can we prove this statement in AdS/CFT?

Every parameter in quantum gravity is an expectation value of a **dynamical field** and can be varied by changing its expectation value.

If there is a **parameter in gravity** in AdS, there must be a corresponding parameter in the dual CFT.

If the CFT parameter can be deformed by adding an exactly marginal operator to the CFT Lagrangian, there must be a **dynamical field** in AdS.

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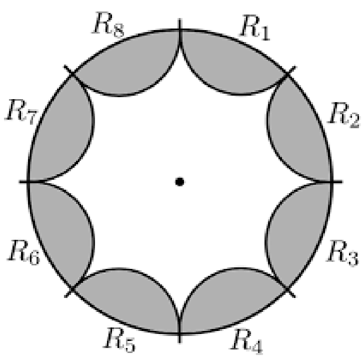
This conditional clause is a conjecture in CFT.

Can every CFT parameter λ be deformed by adding an exactly marginal operator ϕ to the CFT Lagrangian?

$$S_{\mathrm{CFT}} \longrightarrow S_{\mathrm{CFT}} + \delta\lambda \int_{\mathbb{R}\times\Sigma} \phi$$

This is analogous to the Noether theorem,

Splittablity: $U(g,\Sigma) = \prod_i U(g,\Sigma_i)$ when $\Sigma = \cup_i \Sigma_i$,



which was used to prove no global symmetry in quantum gravity.

Harlow, H.O.: 1810.05338

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$$S_{\mathrm{CFT}} \longrightarrow S_{\mathrm{CFT}} + \ \delta\lambda \int_{\mathbb{R}\times\Sigma} \phi$$

This can be regarded as the Noether theorem for a (-1)-form symmetry.

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$$S_{\mathrm{CFT}} \longrightarrow S_{\mathrm{CFT}} + \delta\lambda \int_{\mathbb{R}\times\Sigma} \phi$$

This can be regarded as the Noether theorem for a (-1)-form symmetry.

No parameter in quantum gravity $\Longleftrightarrow$ **No** (-1)-form **global symmetry** in quantum gravity

Snowmass White Paper:
The Analytic Conformal Bootstrap

Hartman, Mazáč, Simmons-Duffin, Zhiboedov

"New methods are needed to take advantage of the vast additional data encoded elsewhere in the conformal manifold, and to address questions about the manifold itself, such as whether there are universal properties of CFTs at infinite distance."

Problem 1: When a unitary CFT has a continuous parameter, show that there is an exactly marginal operator generating its deformation.

Problem 2: Find out whether there are universal properties of CFTs at infinite distance in the conformal manifold and, if so, quantify the properties.

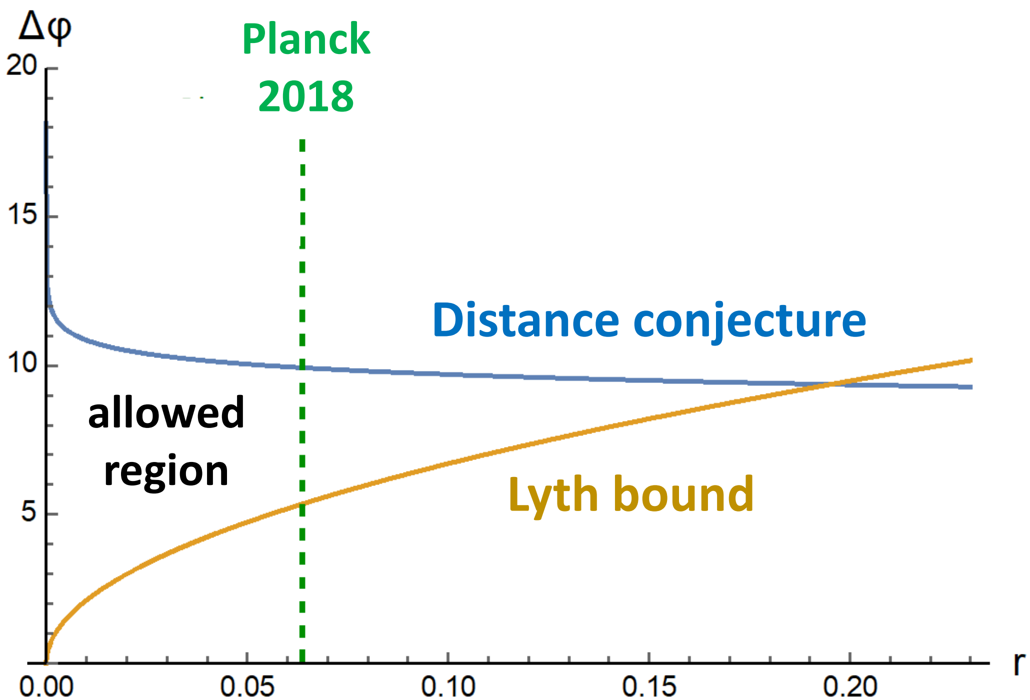
Snowmass Report, Theory Frontier 1 [draft]
Quantum gravity, string theory, and black holes

Conveners: Harlow, Kachru, Maldacena

“One question of great experimental and theoretical interest is whether quantum gravity can produce inflationary models with relatively large values of r, the tensor to scalar ratio. … it is possible that there is a **theoretical upper bound for r** and it would be very interesting to understand where it is.”

My conversation with the Chair of Caltech's Division of Physics, Mathematics and Astronomy in February 2014:

Chair, "BICEP2 is going to announce that r is 0.2."
H.O, "Great. It will kill string theory."



Scalisi, Valenzuela:
1812.07558

Snowmass White Paper:
Implications of Quantum Gravity for Particle Physics

Draper, Garcia Garcia, Reece

"…, we would emphasize that even 'large-field inflation,' where observable tensor modes could be correlated with a Planck-scale field space distance, only requires (to fit cosmological data) that $\Delta\phi \sim O(1)\, M_{\rm Pl}$ and could be entirely consistent with this bound."

A Panorama of Physical Mathematics 2021 [draft]

an extended version of the Snowmass white paper on physical mathematics

Bah, Freed, Moore, Nekrasov, Razamat, Schäfer-Nameki

"When [the distance conjecture] is made mathematically precise in the context of Calabi-Yau compactification some **very nontrivial mathematics emerges**."

Finite G_{Newton} $\Longleftrightarrow$ **Compact** Calabi-Yau

Finite G_{Newton} $\Longleftrightarrow$ **Compact** Calabi-Yau

There are many important questions on physics and mathematics of compact Calabi-Yau manifolds, and we need stronger tools to address them.

In topological string theory, for example:

For **non-compact** Calabi-Yau's, there are many tools, such as the topological vertex and matrix models.

For **compact** Calabi-Yau's, the BCOV equations uniquely determine amplitudes up to $g \leq 51$ in some of the most favorable cases.

Even in this short story on string theory from my narrow perspective, concepts from a variety of different areas are connected.

The study of the **distance conjecture** has been informed by black holes, wormholes, holography, conformal field theory, generalized symmetry, bootstrap, physical mathematics, and so on, and may inform cosmology.

Generalized symmetry

Physical mathematics

Quantum information

Black boles

Cosmology

Even in this short story on string theory from my narrow perspective, concepts from a variety of different areas are connected.

Particle physics

Higher spin

A much wider range of topics is discussed in the cornucopia of Snowmass white papers.

Moonshine

S-matrix bootstrap

Many-body quantum system

Quantum field theory

Scattering amplitudes

Conformal bootstrap

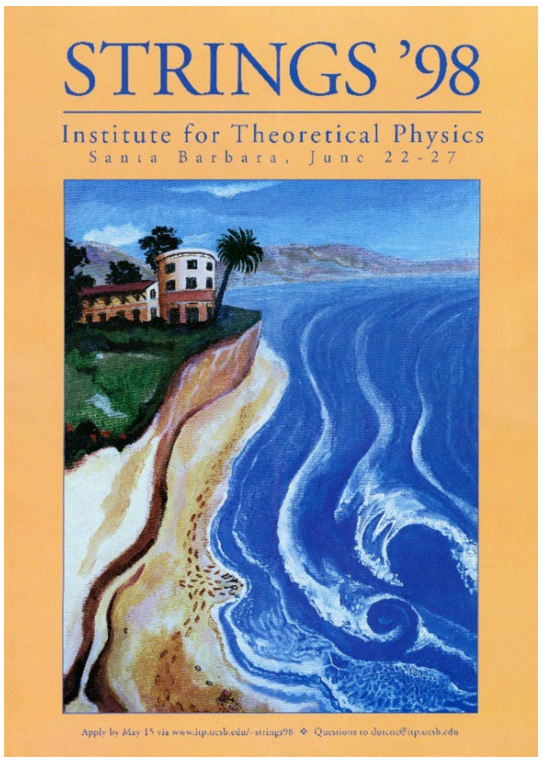
Superconformal field theories

Perturbation theory

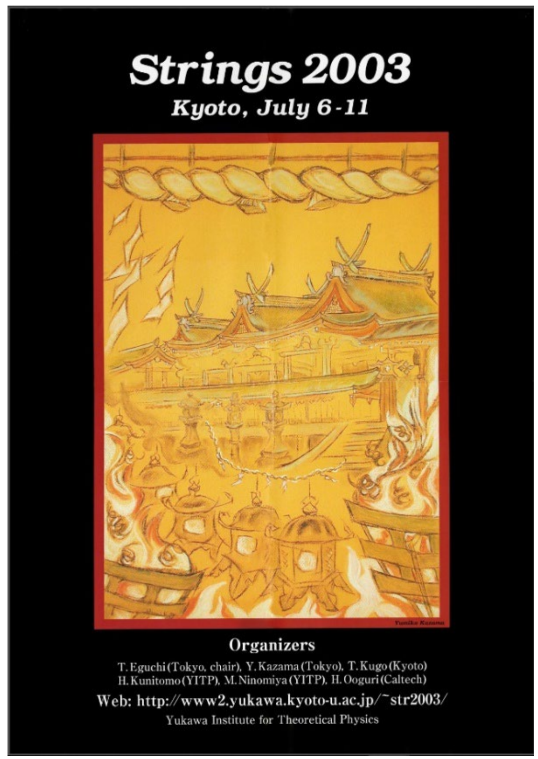
For more than 30 years, the Strings conference series has been providing a unique opportunity for us to come together as a community, to hear about the latest developments on all aspects of string theory, to exchange ideas, and to open new directions of research.

Future of
Strings Conferences

This is **not** an announcement to host Strings 2023 at Caltech.



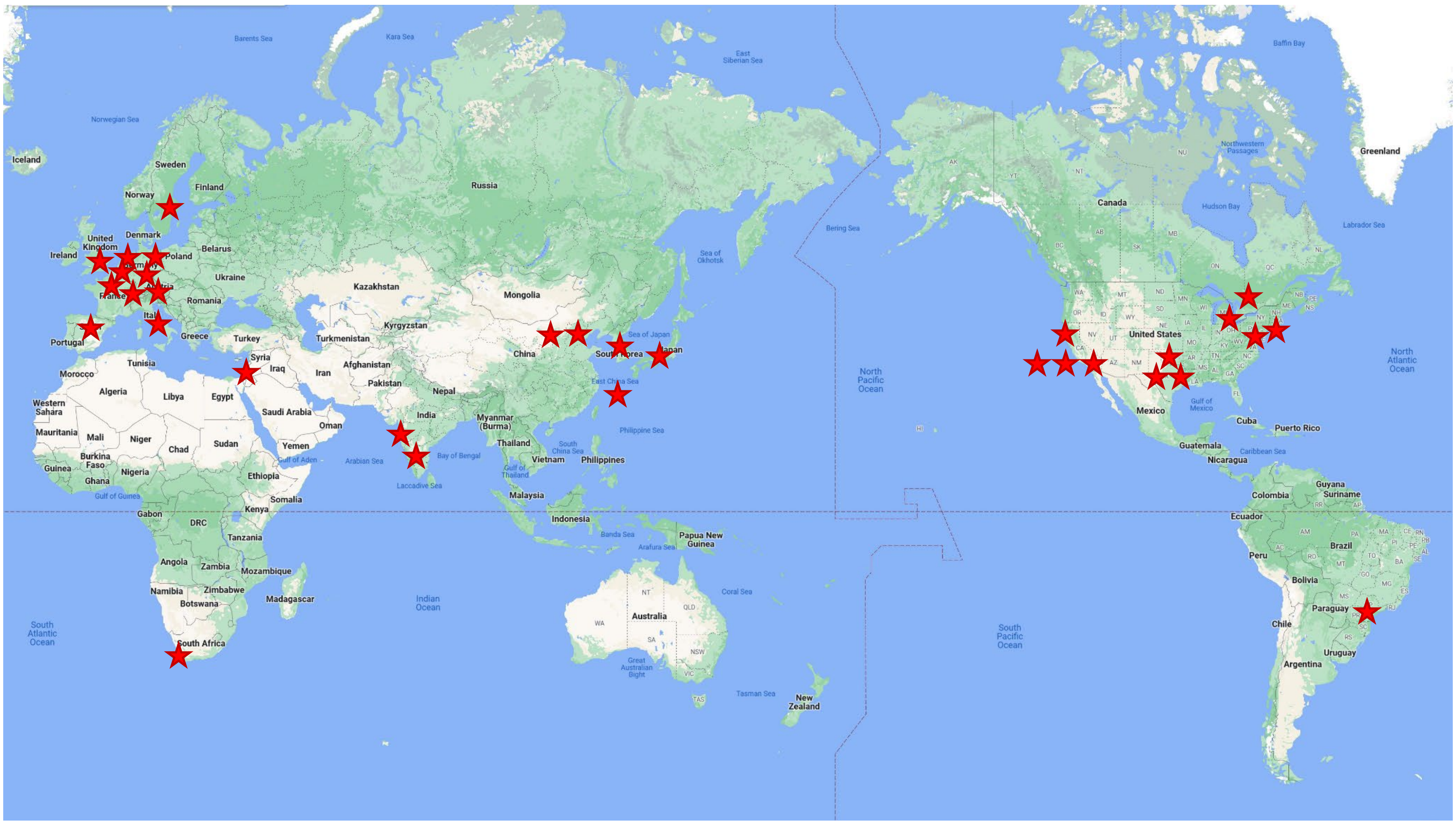
Santa Barbara



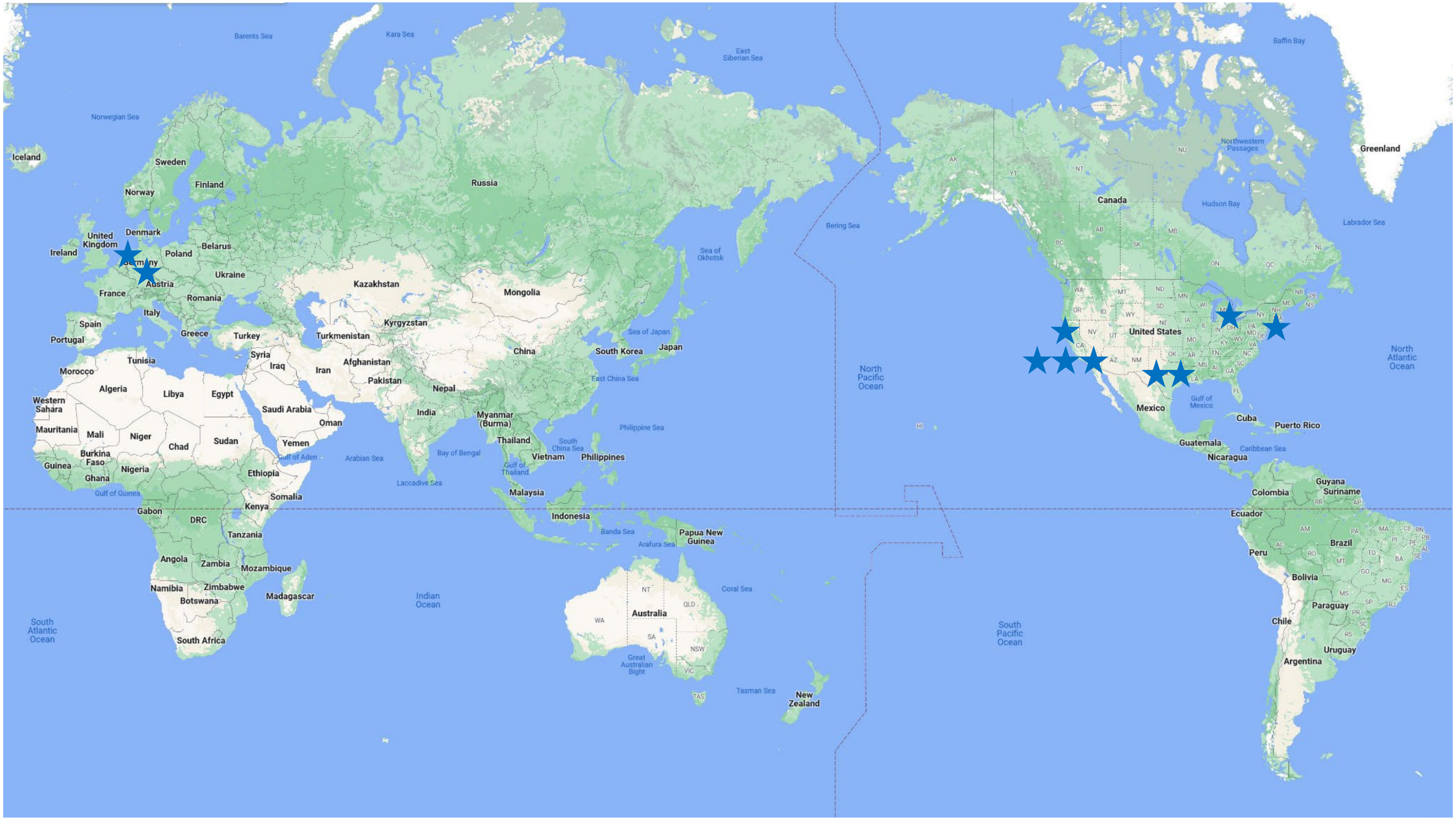
Kyoto

Okinawa

Strings Conferences in 1989 – 2022



1989 - 2000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Western Sahara
Saudi Arabia
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Mali
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Yemen
Gulf of Aden
Arabian Sea
Bay of Bengal
Myanmar (Burma)
Thailand
South China Sea
Vietnam
Philippines
Philippine Sea
Burkina Faso
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Ethiopia
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Somalia
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Arafura Sea
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Madagascar
Indian Ocean
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South Africa
South Atlantic Ocean
Tasman Sea
New Zealand
Bering Sea
North Pacific Ocean
South Pacific Ocean
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Northwestern Passages
Greenland
Labrador Sea
United States
North Atlantic Ocean
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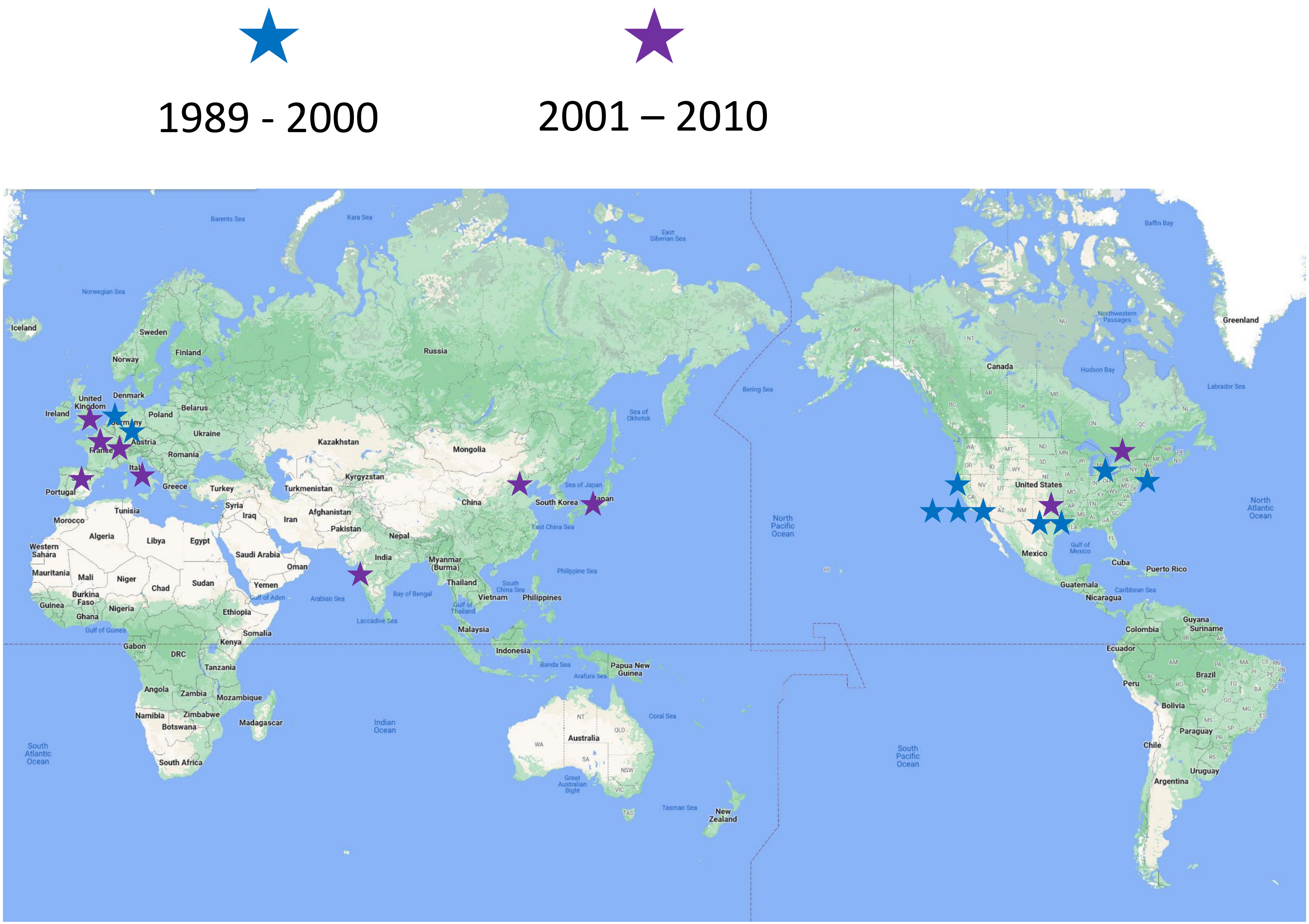
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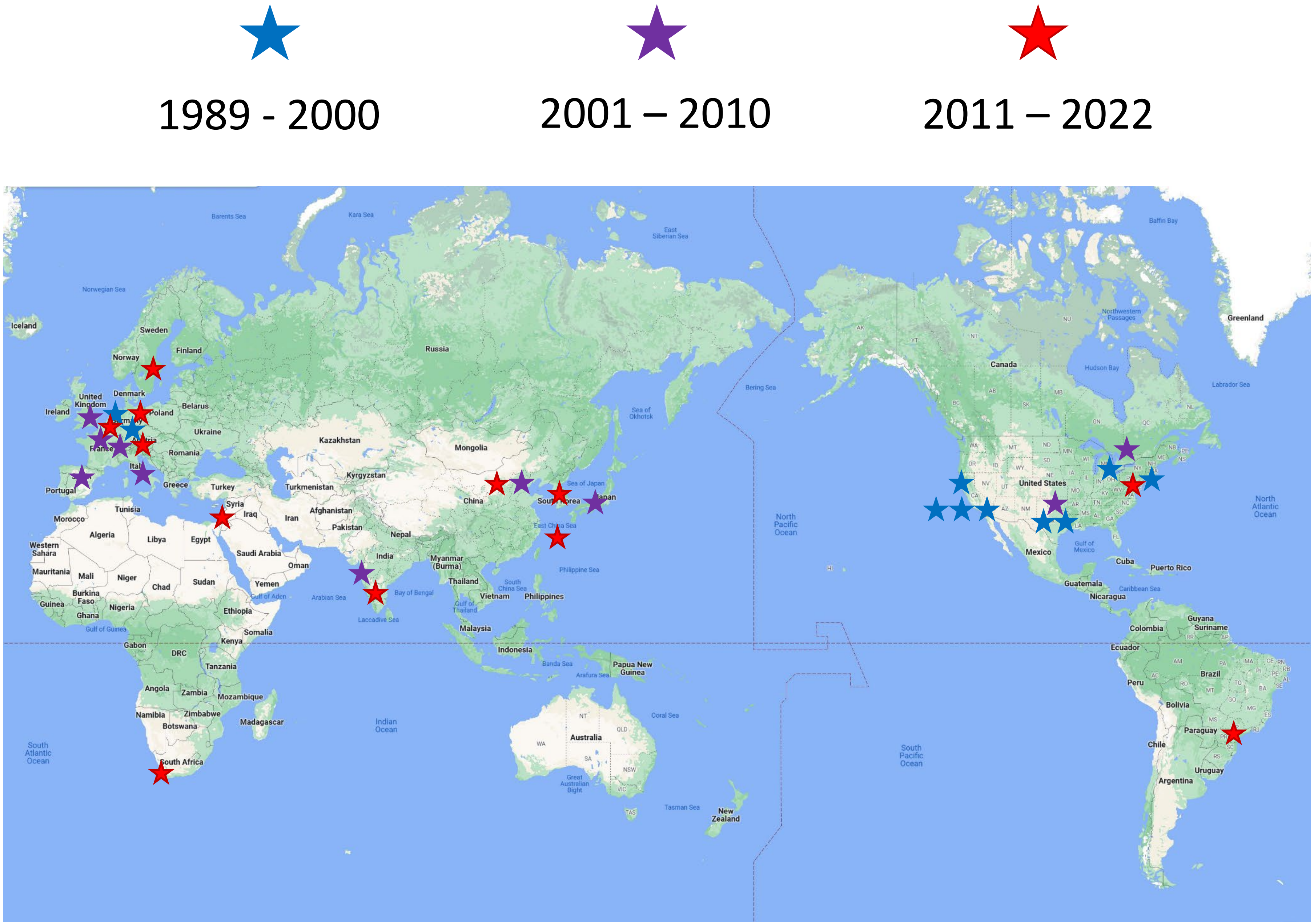

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South Africa
Kazakhstan
Turkmenistan
Kyrgyzstan
Afghanistan
Pakistan
Nepal
India
Mongolia
China
Myanmar (Burma)
Thailand
Vietnam
Philippines
Malaysia
Indonesia
Papua New Guinea
Australia
New Zealand
Canada
United States
Mexico
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Puerto Rico
Guatemala
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Chile
Uruguay
Argentina
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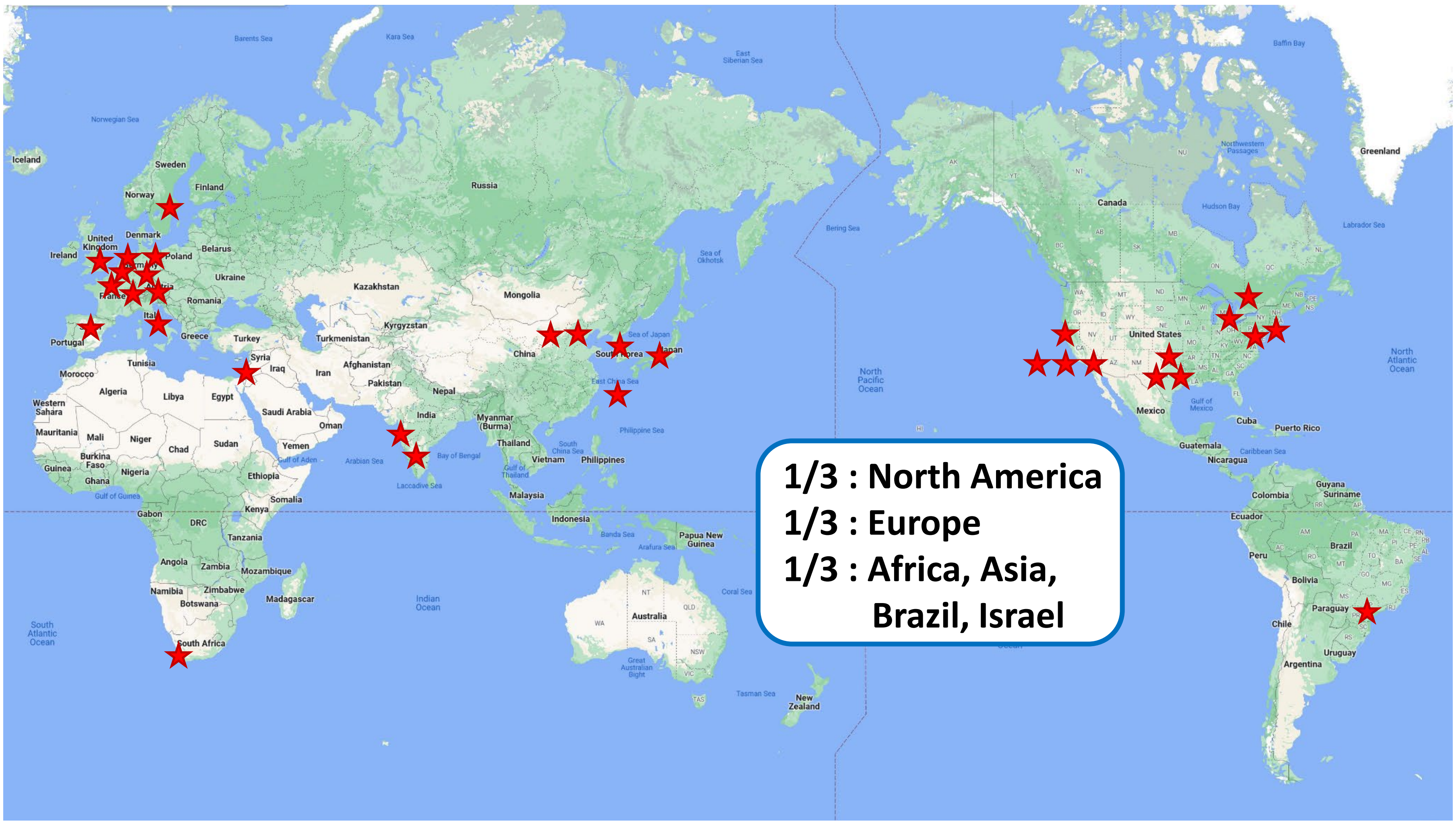
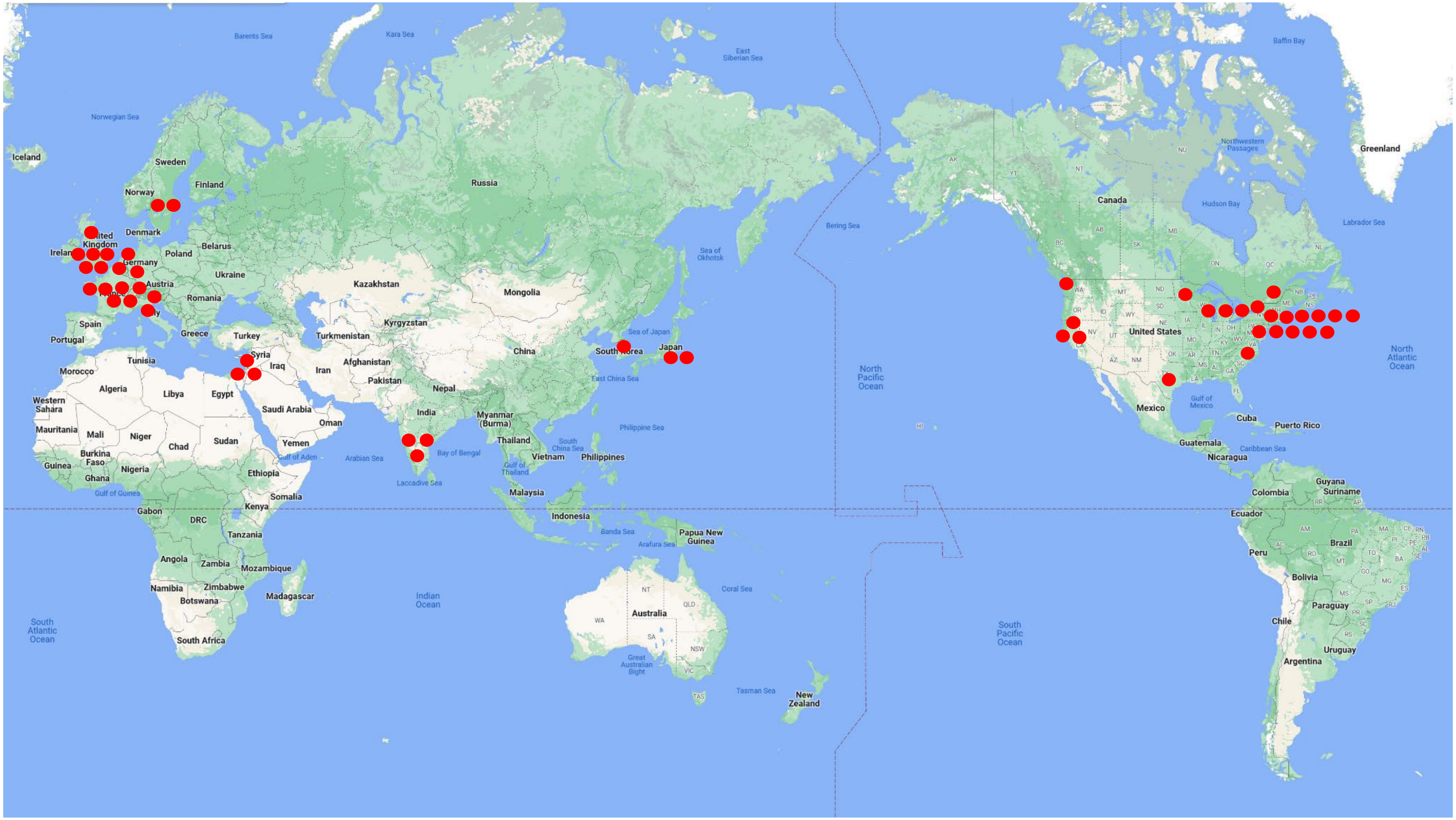
Caribbean Sea

Strings Conferences in 1989 – 2022

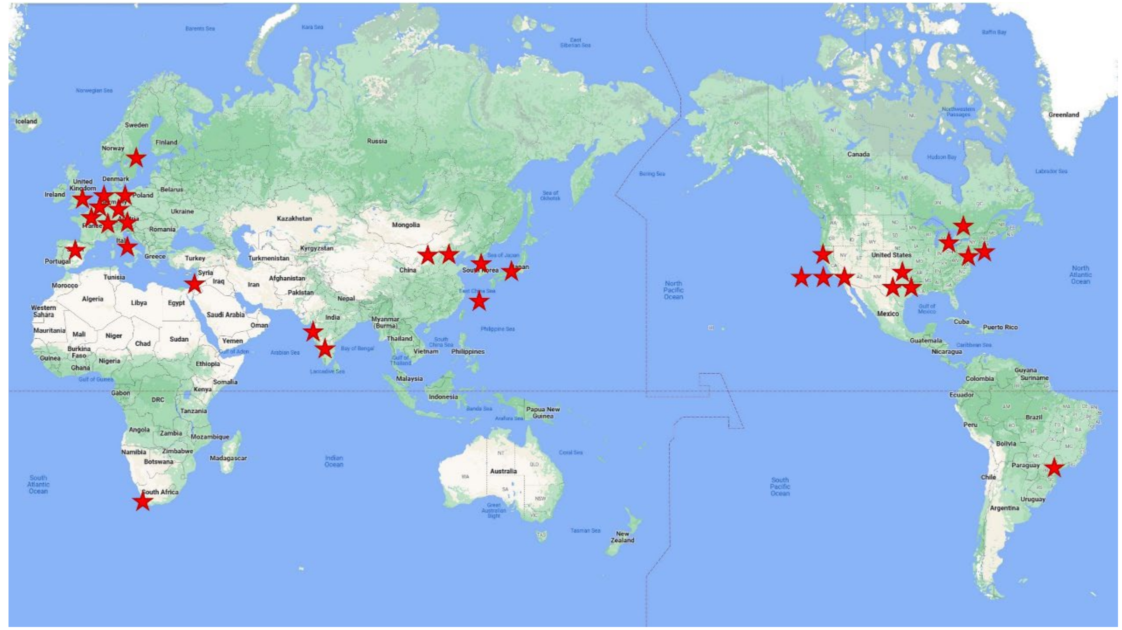


1/3 : North America
1/3 : Europe
1/3 : Africa, Asia, Brazil, Israel

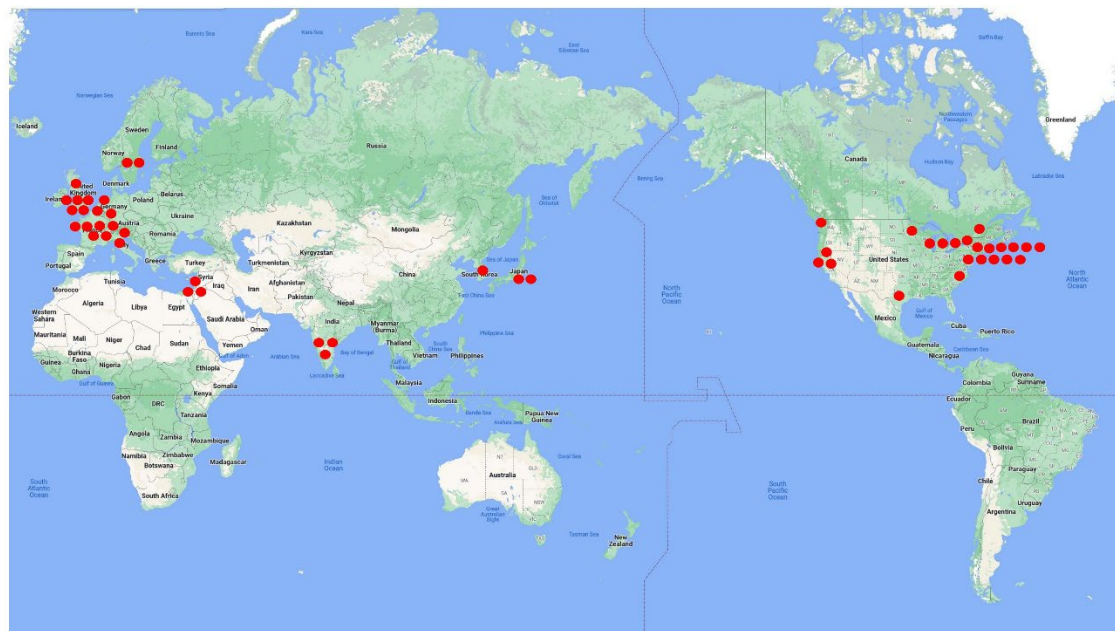
Invited Scientific Speakers of Strings 2022



Strings
1989 – 2022



Strings 2022
Speakers



Issues to consider

- Budget and administrative support.
- Carbon footprint and uses of virtual space.
- Improve the diversity and be welcoming to all members of our community.
- Support for students and postdocs.
- Access from developing countries.
- Process to select and vet future Strings.

Post your comments at:
https://strings2022.zulipchat.com/join/pr2y4ctsdhg7dg3bvgimdz3a/

Sizes of Past Strings Conferences

Strings	Country	Total Expense	Registration	Fundraising	#Participants
2021	Brazil	2K USD	—	—	2,480
2020	South Africa	3K USD	—	—	2,353
2019	Belgium	335K Euro	95K Euro	260K Euro	492
2018	Japan	510K USD	60K USD	450K USD	400
2017	Israel	260K USD	55K USD	205K USD	301
2016	China	200K USD	50K USD	150K USD	460
2015	India	220K USD	60K USD	160K USD	296
2014	USA	350K USD	132K USD	218K USD	600
2013	South Korea	200K USD	50K USD	150K USD	280
2012	Germany	200K Euro	45K Euro	115K Euro	400

From my summary talk at Strings 2021:

> The organization of this year's Strings conference has been amazing. I have never before seen this level of open, honest, reflective discussions in a conference with 300+ live participants.

Facebook post by a distinguished string theorist

Virtual

- $5 \times$ participants ($2 \times$ live participants) with $1/100$ of cost.
- Reduce carbon footprints.
- On-line discussions encourage participations of young researchers.
- Accessibility.

Real

- Chance encounters, small talks, and silly questions often lead to important new insights and open new directions of research.
- Networking opportunities for young and not-so-young researchers.
- Comradery.

virtually

Dates to be announced

String Pheno 2023

3 – 7 July in Daejeon, Korea

String Math 2023

10 – 14 July in Melbourn, Austraria

Strings Vienna, 2022

18-22 July

Acknowledgments

Thank you!

Scientific Committee*

Chair: Johanna Erdmenger

Ofer Aharony, Netta Engelhardt,
Jan de Boer, Jerome Gauntlett, Veronika Hubeny,
Andrea Puhm, Suvrat Raju, Sakura Schäfer-Nameki,
Harald Skarke, Julian Sonner, Pedro Vieira

* started at Strings 2018 in Okinawa

Gong Show Selection Committee

Nils Carqueville, Laura Donnay, Jan Rosseel,
Harold Steinacker

Thank you!

Anton Rebhan of TU Wien

and ∫dkΠ Doktoratskolleg Particles and Interactions

for hosting the public lecture by Netta Engelhardt:

“The Black Hole Information Paradox:
A resolution on the horizon?”

tonight at 7 pm, Festival room of the Austrian Academy of Sciences

Thank you!

Local Organizing Committee

universität wien

Veronika Bachleitner, Caslav Brukner, Nils Carqueville,
Stefan Fredenhagen, Olaf Krüger, Max Riegler, Timon Zipfelmaier

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Rohan Poojary, Anton Rebhan, Romain Ruzziconi,
Harald Skarke, Andrea Smith-Stachowski, Raphaela Wutte

KAVLI IPMU Abhiram Kidambi

Jakob Salzer

Thank you!

Main Organizers

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Daniel Grumiller

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