An overview of high-energy theoretical physics (hep-th) in Israel

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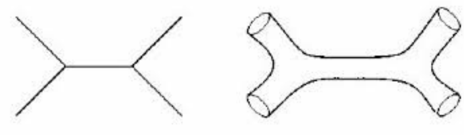
Overview of “The Big Questions”

Strongly Coupled Quantum Field Theory

- **Quantum Field Theory** (QFT) is an enormously successful framework, but we still know relatively little about the behavior of QFTs at strong coupling.
- Main motivations to understand these come from QCD (understand confinement, spectrum of mesons/baryons, ...) and from condensed matter systems.
- Some direct impact on particle physics (hadronic matrix elements; hadronization). May also have applications to physics beyond the standard model, which may or may not involve strongly coupled QFTs.
- Many methods involve studying toy models (SUSY theories, theories with weakly curved holographic gravity duals, large N theories, ...), hoping to learn general lessons.

Some specific "Big Questions" that people raised :

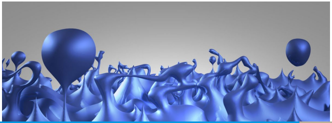
- Can we find a dual string theory description for QCD (weakly coupled in the large N limit) that would explicitly show confinement ? So far slow progress in string duals to related theories (e.g. 2d YM/QCD, SUSY theories).



- Can we classify all conformal field theories (end-points of RG flows in particle physics / statistical mechanics, essentially same as classifying all QFTs) ? New methods developing, but still far from full classification (even in 1+1 dimensions).

Quantum Gravity

- By now understand quite well **quantum gravity** (QG) in 1+1 dimensions (where gravitational path integral makes sense), and in higher dimensions with negative cosmological constant (AdS/CFT, gravity arises as effective theory, equivalent to a QFT in one dimension lower).
- Slow progress in understanding general features of QG in Minkowski space or cosmological backgrounds / de Sitter space.
- Motivation mostly theoretical, but can hope ("swampland program") that consistency with QG imposes also constraints on phenomenology (e.g. all global symmetries broken at Planck scale).



Quantum Gravity II

Some specific “Big Questions” that people raised :

- Can we understand quantum gravity in flat space / expanding universes ? Even the structure of the Hilbert space is not yet clear; since QG is highly non-local understanding it in some backgrounds does not immediately help in others.
- Can we understand the microstructure of realistic black holes, e.g. what happens when crossing the horizon (still not clear) ?
- Can UV/IR connections in gravity (“swampland program”) teach us about the hierarchy problem and/or the cosmological constant problem ? Can we say anything about the baryon assymetry / dark matter / the cosmological constant ?
- Does QG involve some “ensemble averaging” ?

Specific topics that people are working on

QFT – general

- QFTs (in particular CFTs) with defects and interfaces.
- Generalized symmetries (higher-form, non-invertible).
- Strongly coupled dynamics – in supersymmetric theories (relations to geometry), onset of confinement in QCD_4 and QCD_3, $\cdots$
- Quantum information and quantum chaos in QFT.
- String theory descriptions of 2d Yang-Mills/QCD.
- Out-of-equilibrium physics (turbulence, phase transitions in expanding medium).
- QFT in de-Sitter space.
- Deep learning and quantum information science applied to hep-th problems.
- Dynamics of non-relativistic anyons.
- Knotted non-Abelian fields.

QFT – related to particle physics

- Scattering amplitudes (various new methods, e.g. conformal dispersive techniques), new methods to evaluate Feynman integrals.
- Heavy ion physics – holographic descriptions, need a theory of hydrodynamics with spin.
- String-motivated models of hadrons (would be good to have more data on glueballs, tetraquarks, pentaquarks, etc.).
- Implications of generalized symmetries for particle physics ?
- Can useful deep learning / quantum information methods be developed ?

Quantum Gravity – general

- Quantum information / quantum chaos in quantum gravity and in black holes (mostly low-dimensional).
- Swampland program – obtaining constraints on consistent low-energy effective theories.
- Black hole physics – photon ring, charge accumulation, Love numbers, classical dynamics (3-body problem).
- Microscopic structure of black holes.
- Deriving the relation of gauge theories and gravity (first for free theories / 3d CS-matter theories).
- Topological strings.

QG – related to particle physics

- Useful swampland constraints on particle physics ?
- Understand better gravity waves during black hole mergers.
- Can we learn from black hole imaging about near-horizon physics (e.g. condensation of ultralight bosons) ?
- Can understanding QFT/QG in de Sitter space be related to signatures from the early universe, or other cosmological measurements ?

Thanks for listening, hopefully new developments (from experiment/theory) will lead to closer connections in the future...