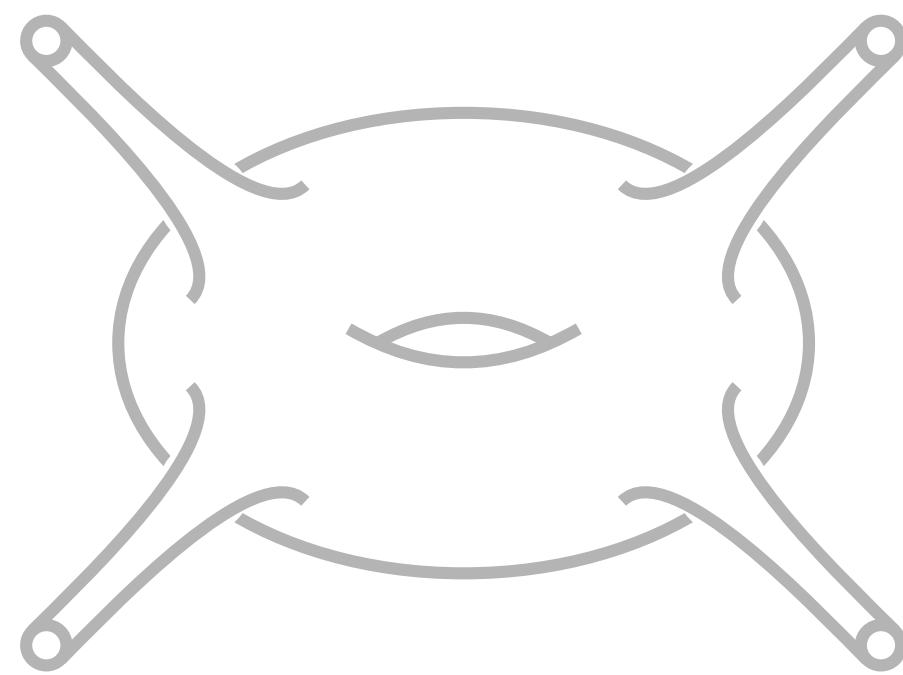
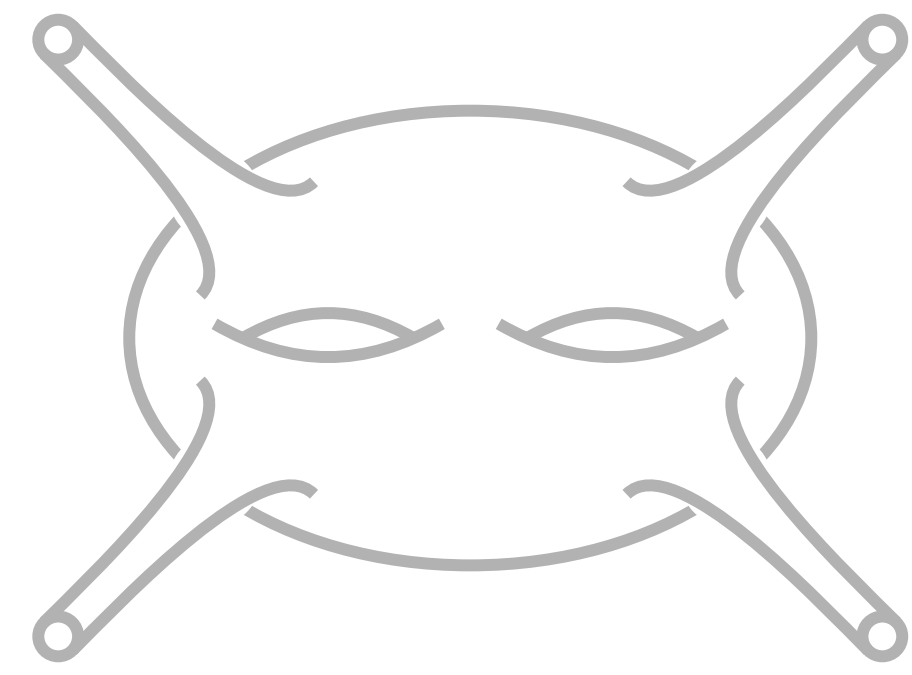


Quantum Gravity in the Collider



Lorenz Eberhardt
University of Amsterdam

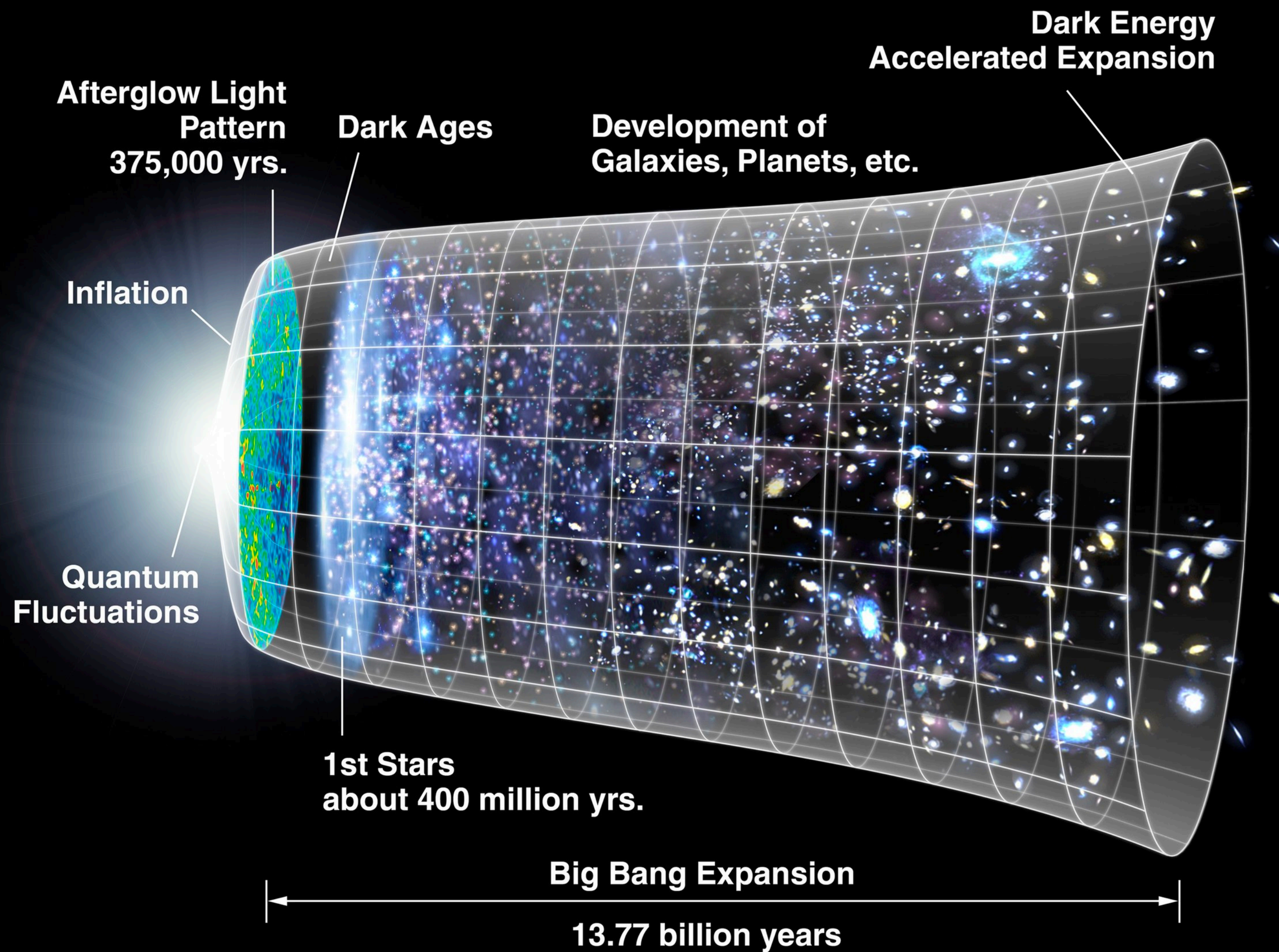


EPS-HEP, 07.07.2025

Many thanks

- To EPS-HEP for the honor of this award
- To all my teachers, collaborators and mentors
- To all my friends all around the world
- To my parents and siblings
- To the people at large, whose generous contribution allows the pursuit of curiosity driven science
- To my wife Elena and son Arthur whose support over the years has been indispensable
- ...

Our life depends on quantum gravity



Theory to the rescue

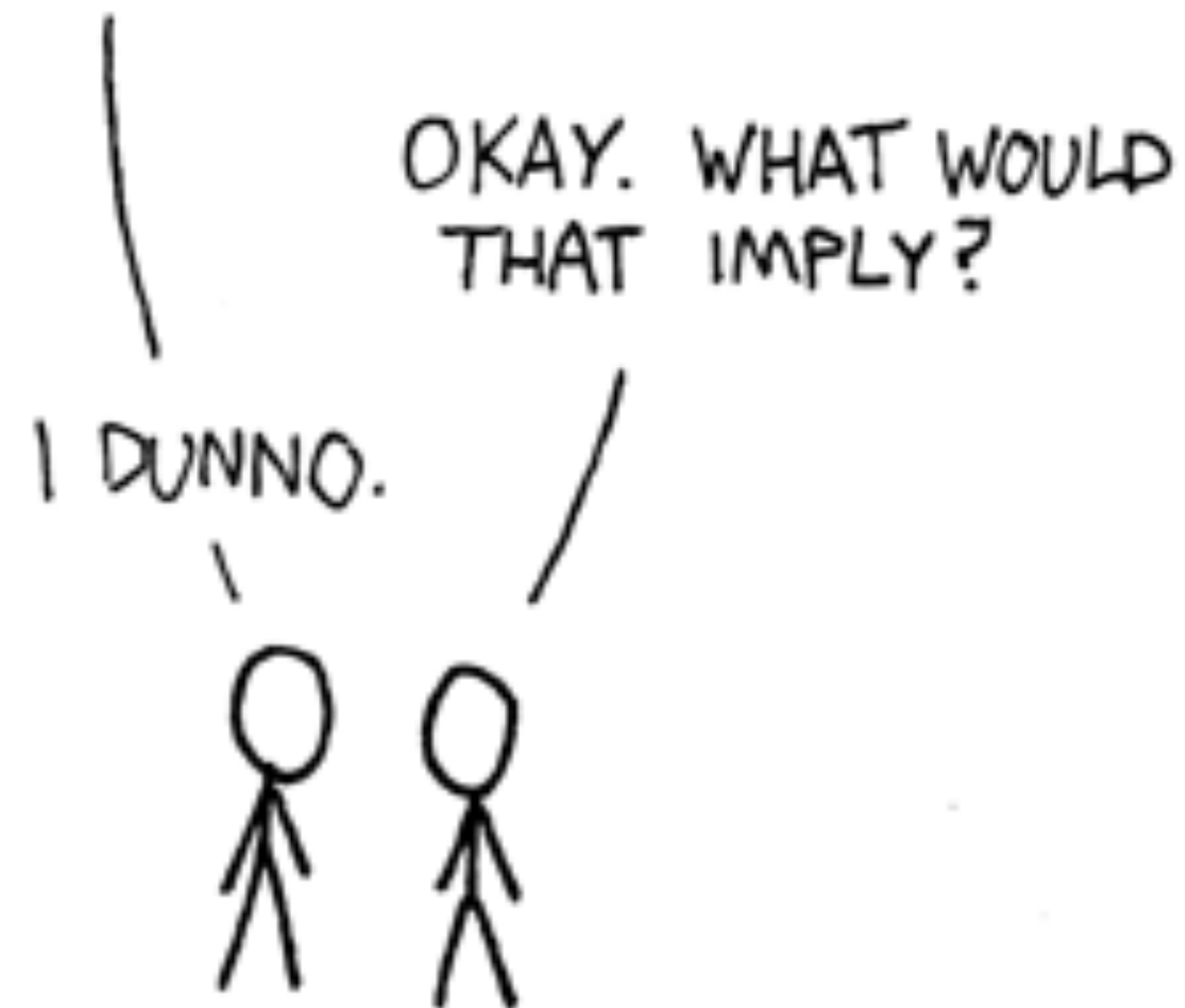
Any theory of quantum gravity has to be

- compatible with all known experimental data
- internally consistent

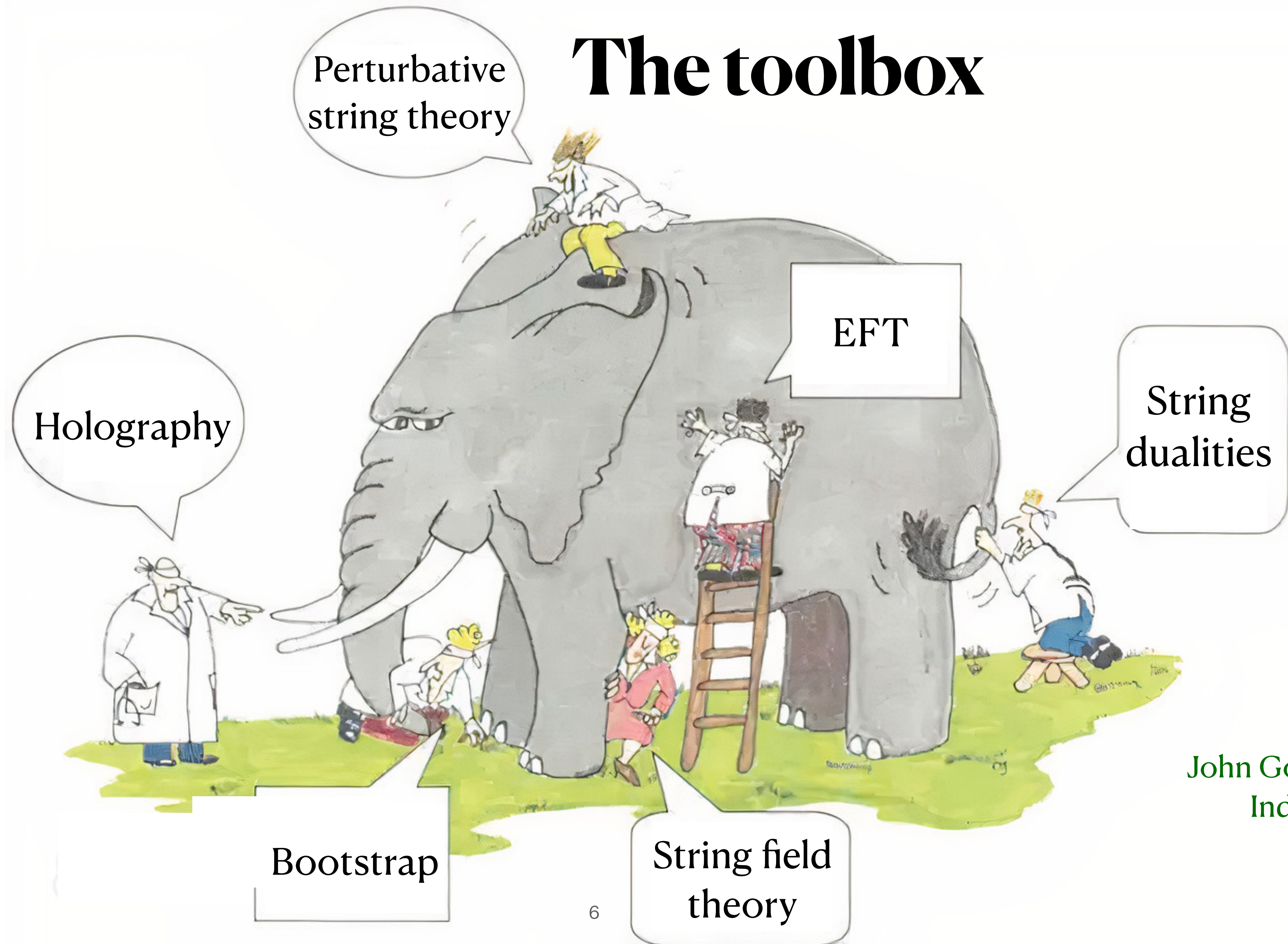
This is a very tall order

STRING THEORY SUMMARIZED:

I JUST HAD AN AWESOME IDEA.
SUPPOSE ALL MATTER AND ENERGY
IS MADE OF TINY, VIBRATING "STRINGS."



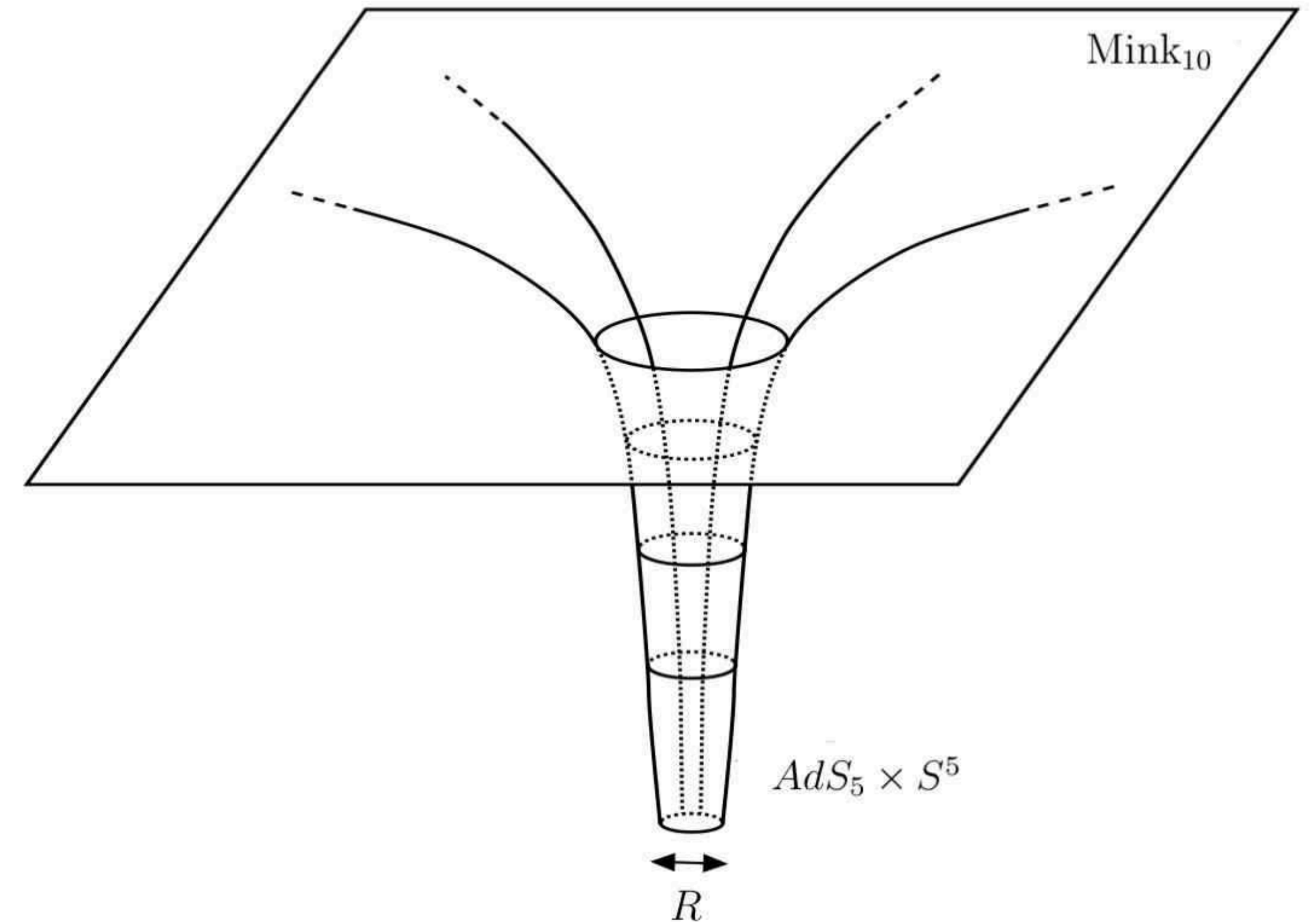
The toolbox



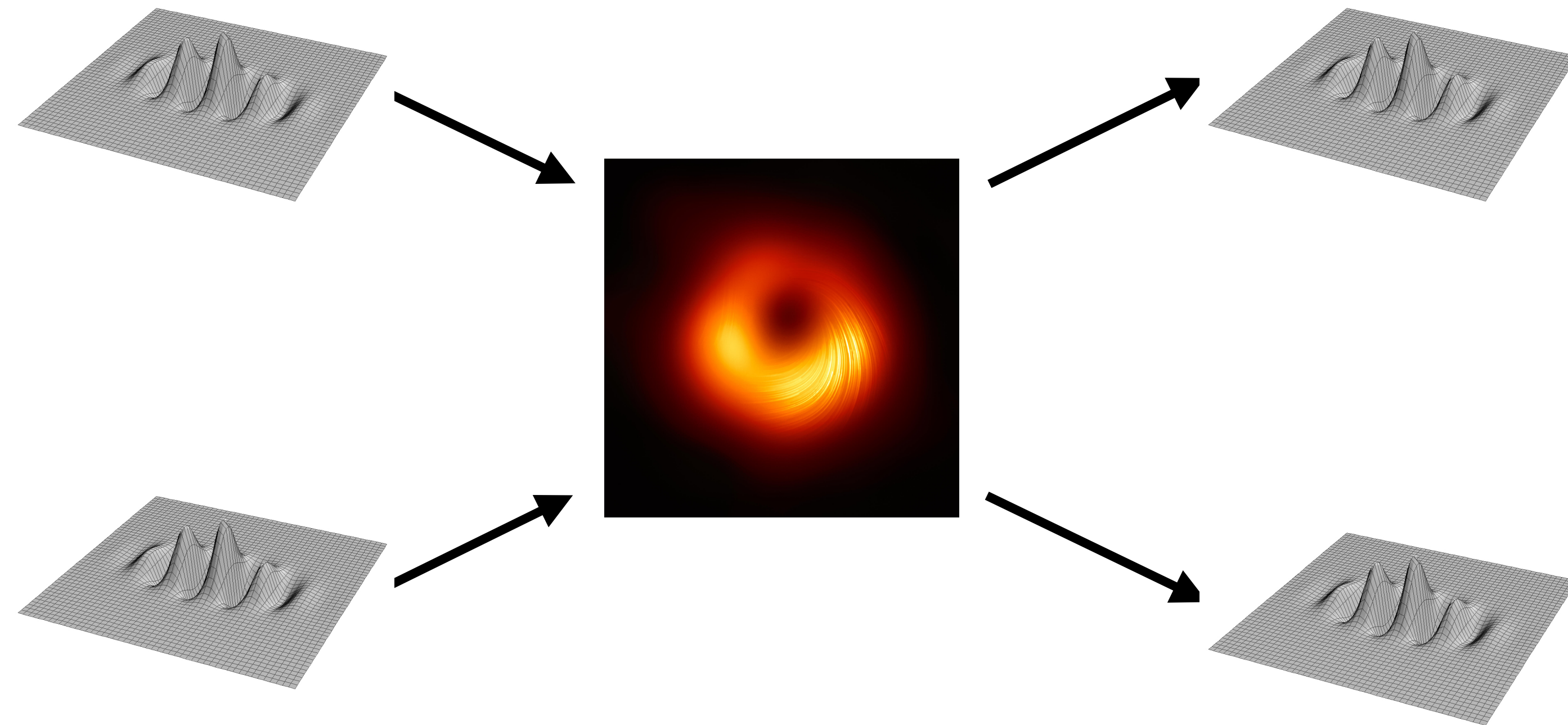
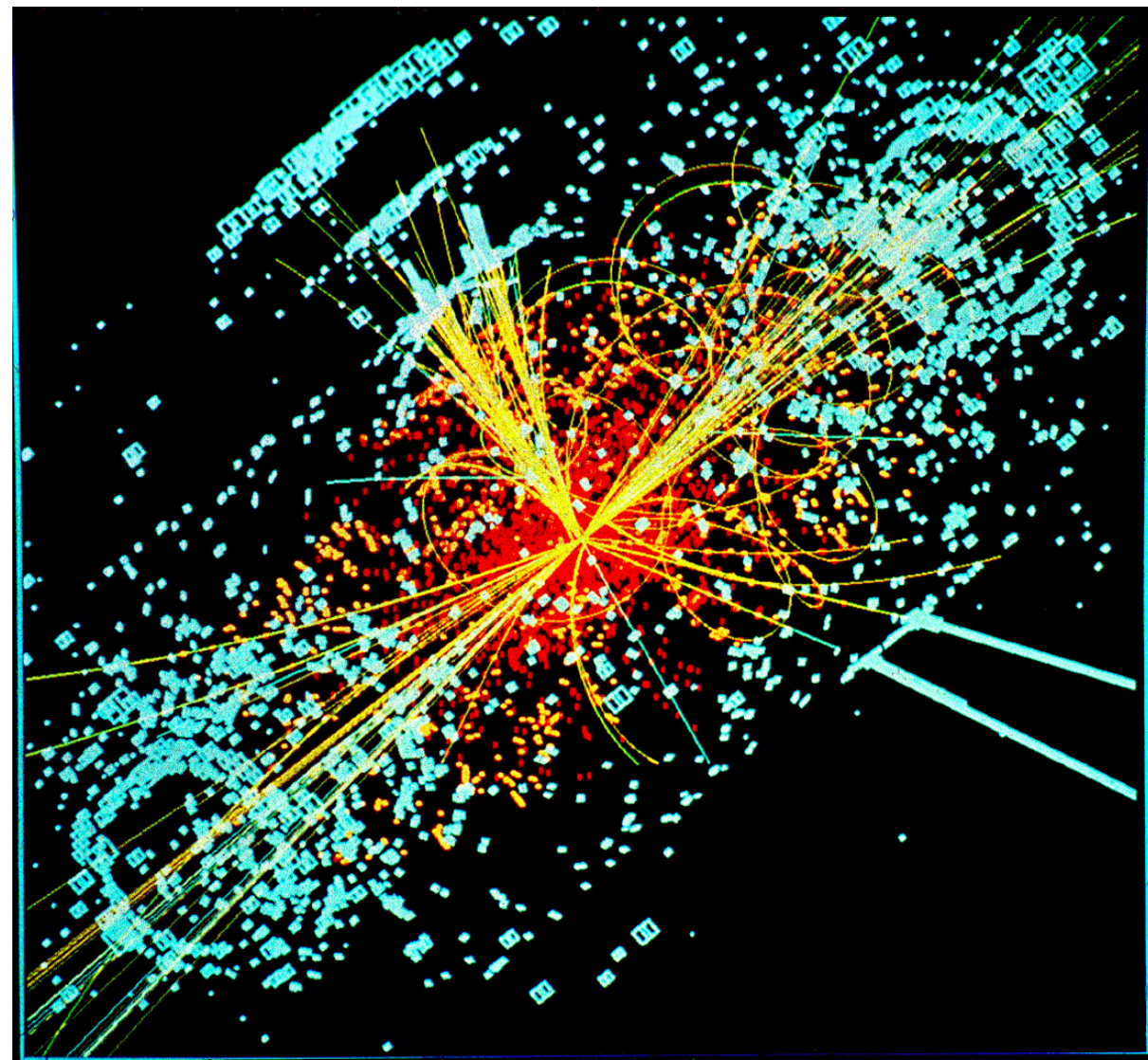
John Godfrey Saxe 1872,
Indian parable

String theory is computationally hard

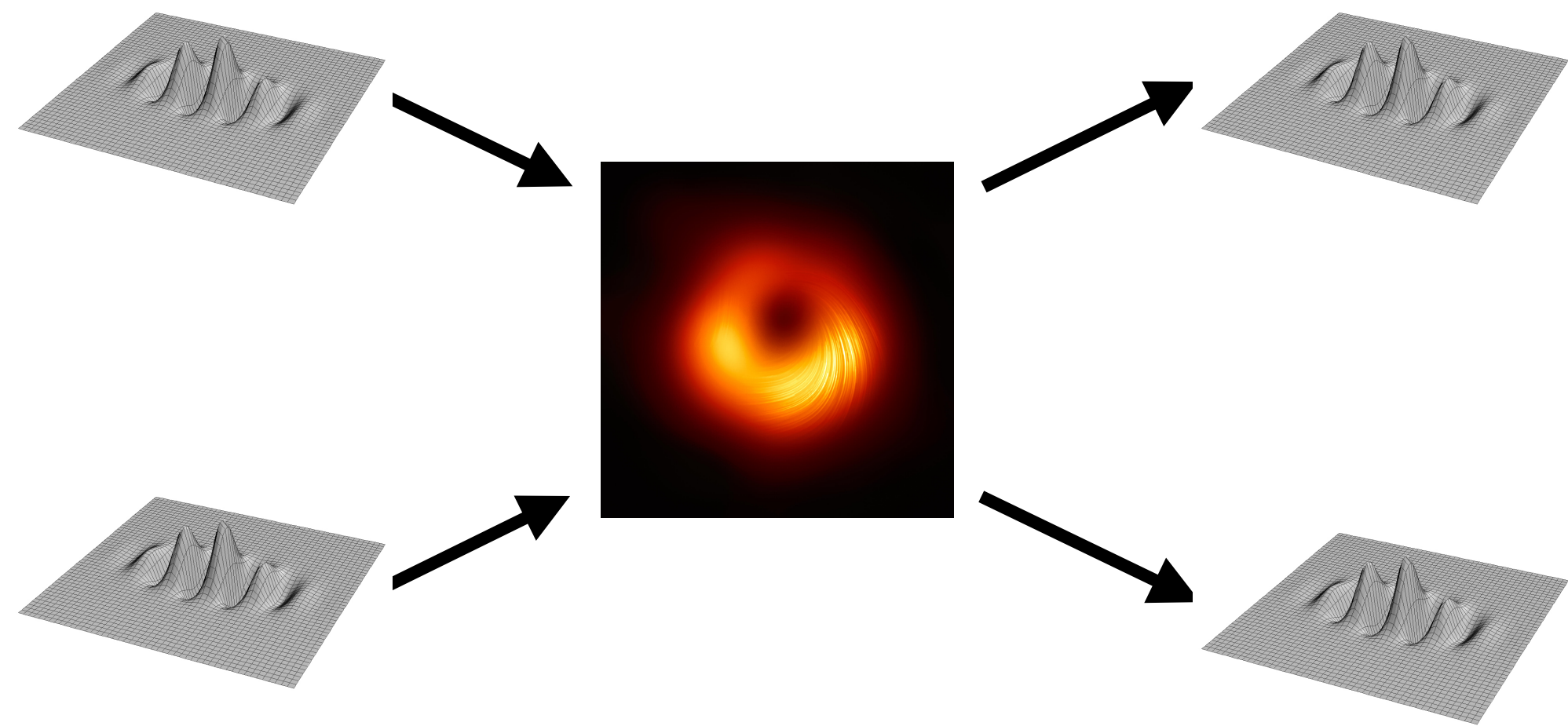
- Highly symmetric situations
- New computational machinery
- Extract general lessons



Quantum gravity in the collider



String theory works just like QFT

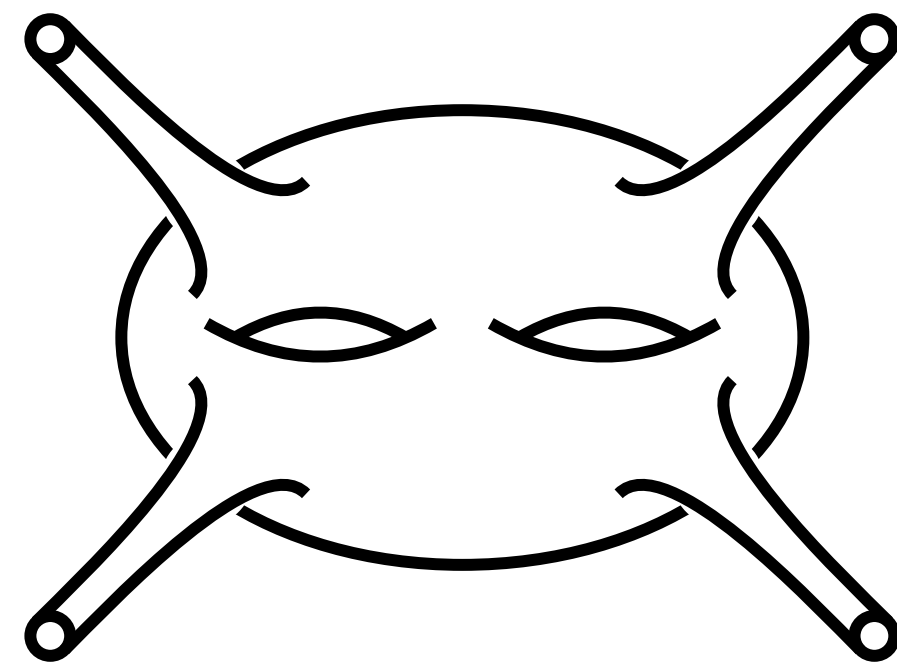


$$= G_N \text{ (tree diagram)} + G_N^2 \text{ (one-loop diagram)} + G_N^3 \text{ (two-loop diagram)} + \dots$$

The equation shows a series of Feynman diagrams representing the perturbative expansion of a scattering amplitude. The first diagram is a tree-level diagram with four external legs and a central vertex. The second diagram is a one-loop diagram with a bubble in the center. The third diagram is a two-loop diagram with two bubbles. The series continues with an ellipsis.

Stringy Feynman diagrams

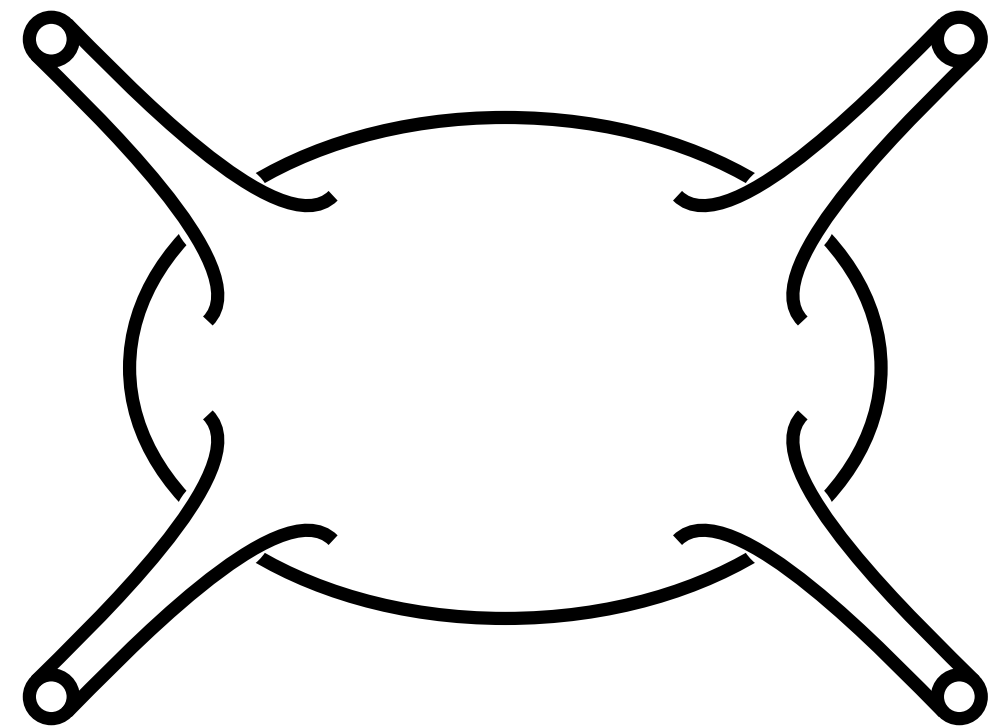
- Only one diagram per loop
- Contains infinitely many massive particles



=

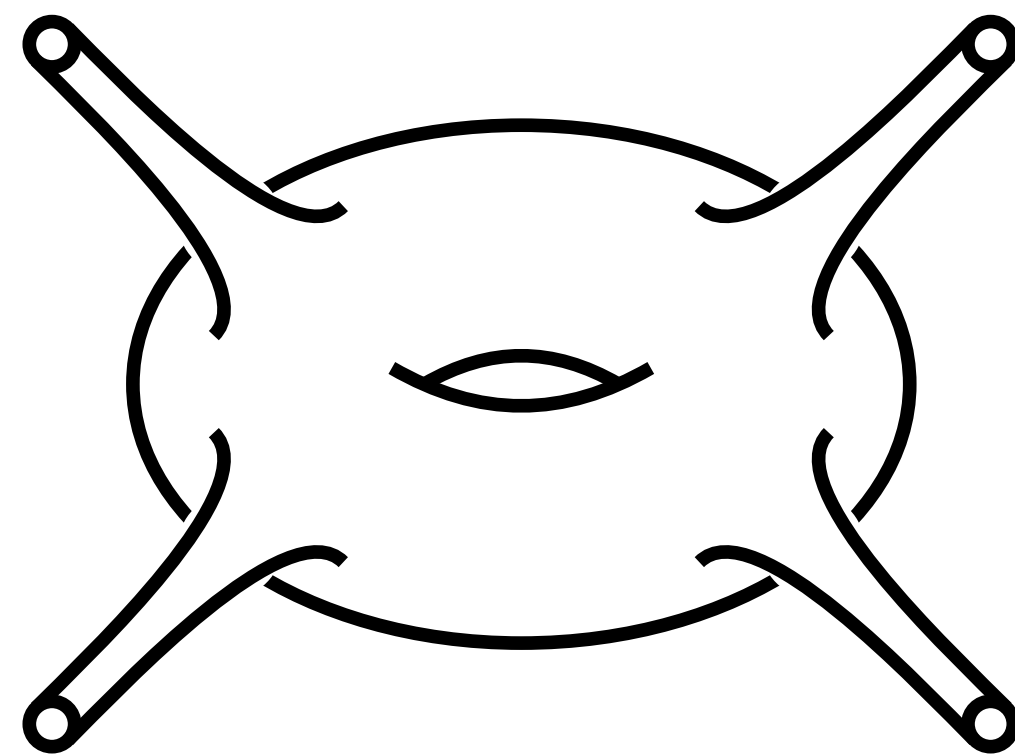
Some complicated
integral

Computing the integrals



$$= (\text{polarizations}) \times \frac{\Gamma(-\frac{\ell_s^2 s}{4})\Gamma(-\frac{\ell_s^2 t}{4})\Gamma(-\frac{\ell_s^2 u}{4})}{\Gamma(1 + \frac{\ell_s^2 s}{4})\Gamma(1 + \frac{\ell_s^2 t}{4})\Gamma(1 + \frac{\ell_s^2 u}{4})}$$

Virasoro - Shapiro amplitude '69

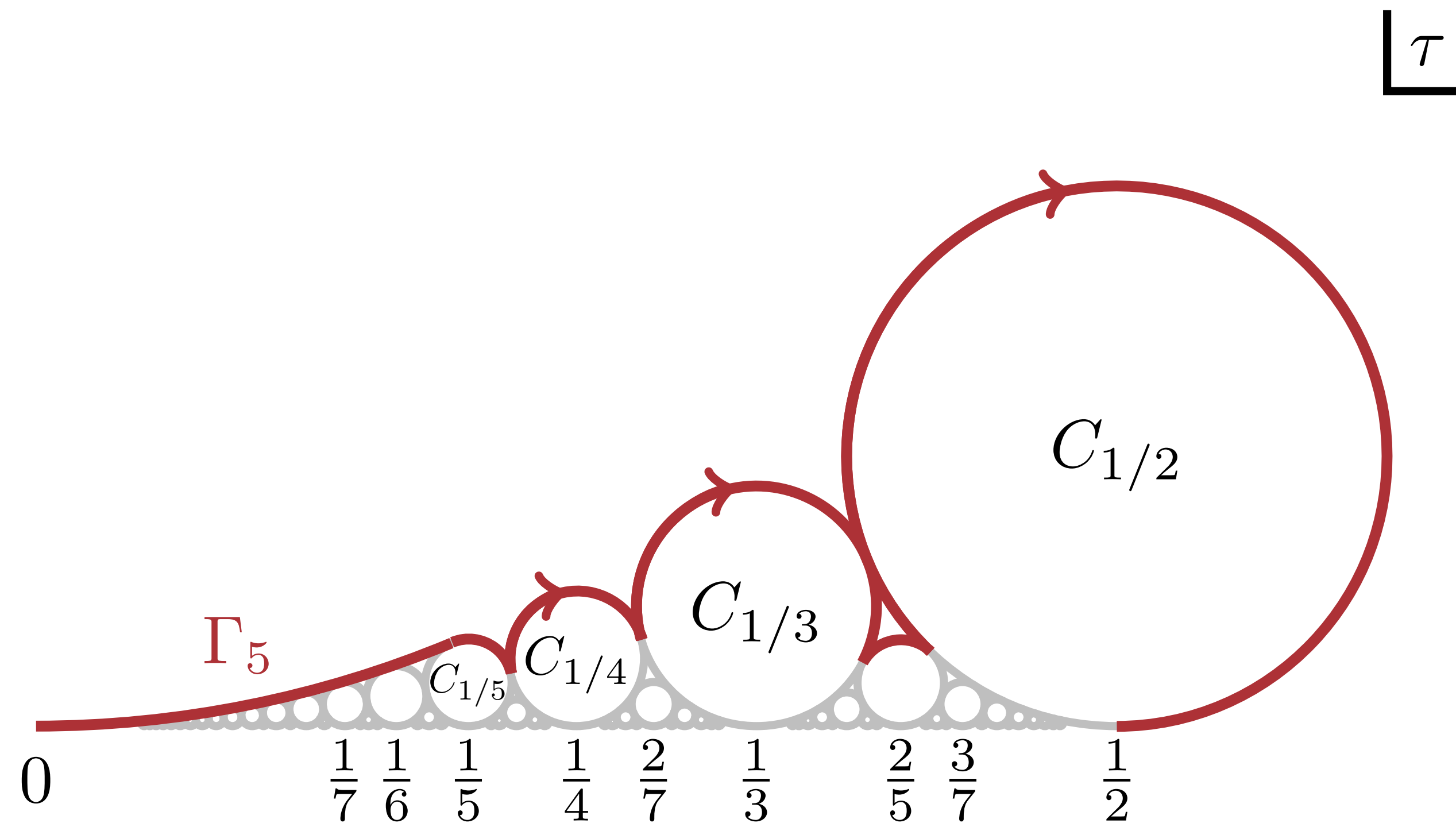


= much more complicated than polylogs...

???

One loop

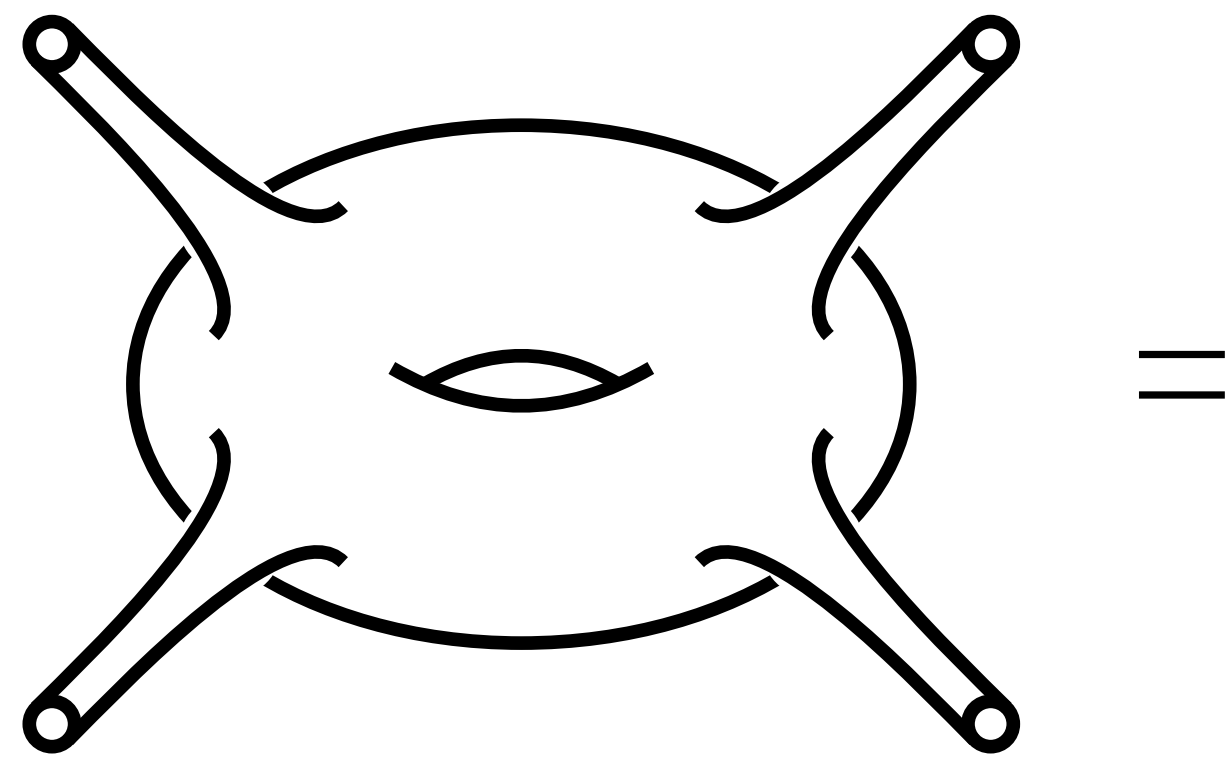
Baccianti, Chandra, **LE**, Hartman, Mizera '22 - ... : Hardy-Littlewood circle method
from analytic number theory can be generalized to compute one-loop diagram



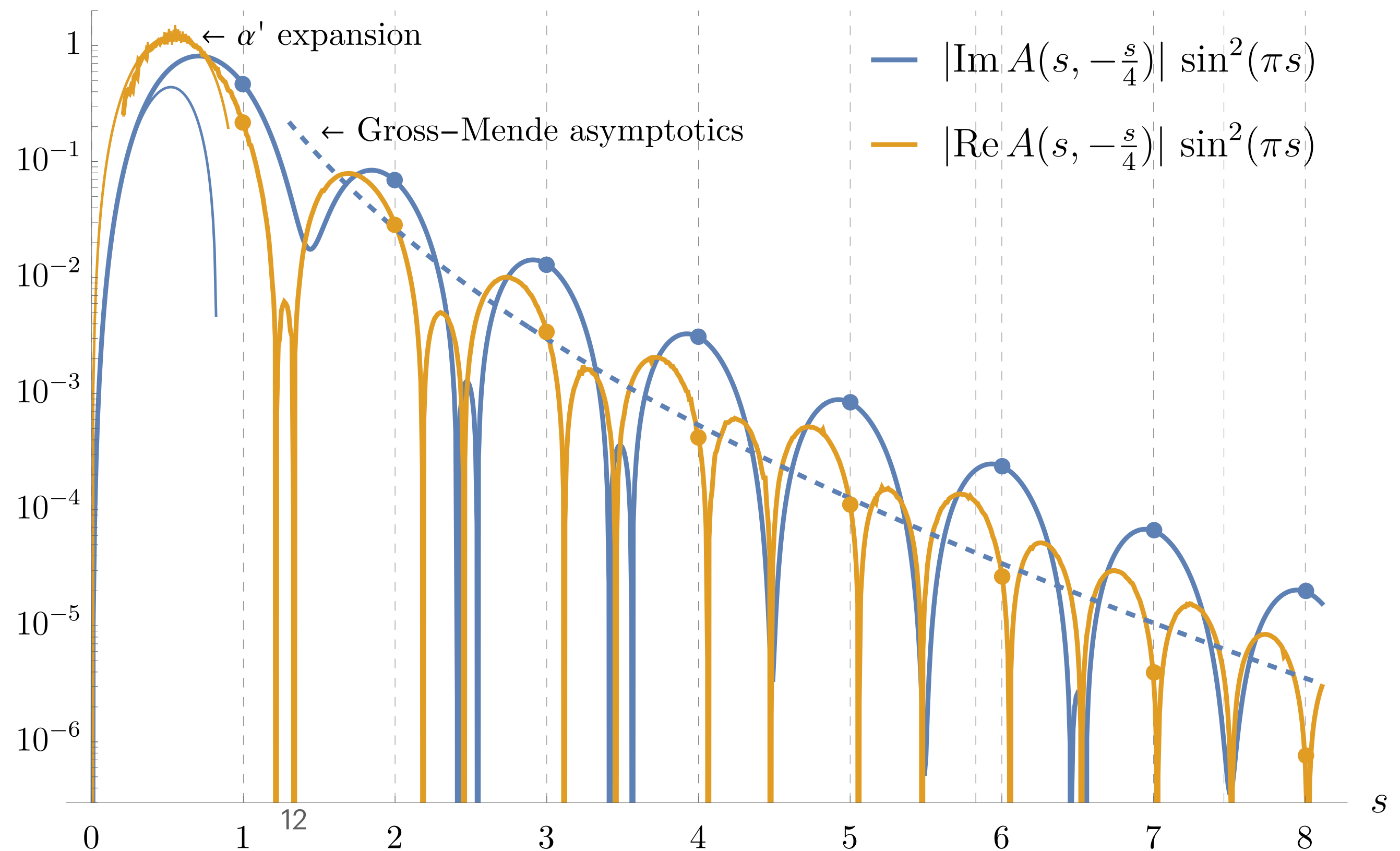
One loop

Baccianti, Chandra, **LE**, Hartman, Mizera '22 - ... : Hardy-Littlewood circle method

from analytic number theory can be generalized to compute one-loop diagram



=



How does string theory differ from QFT?

- UV finite
- Exponentially soft for large energies

$$\mathcal{M}_L \sim \exp\left(-\frac{s}{L+1}f(\theta)\right) \times \text{subleading}$$

Gross, Mende '87

- General feature of string theory!

STRING THEORY SUMMARIZED:

I JUST HAD AN AWESOME IDEA.
SUPPOSE ALL MATTER AND ENERGY
IS MADE OF TINY, VIBRATING "STRINGS."

OKAY. WHAT WOULD
THAT IMPLY?

Perturbative amplitudes are
exponentially soft in the UV
and many other things!



Thank you!