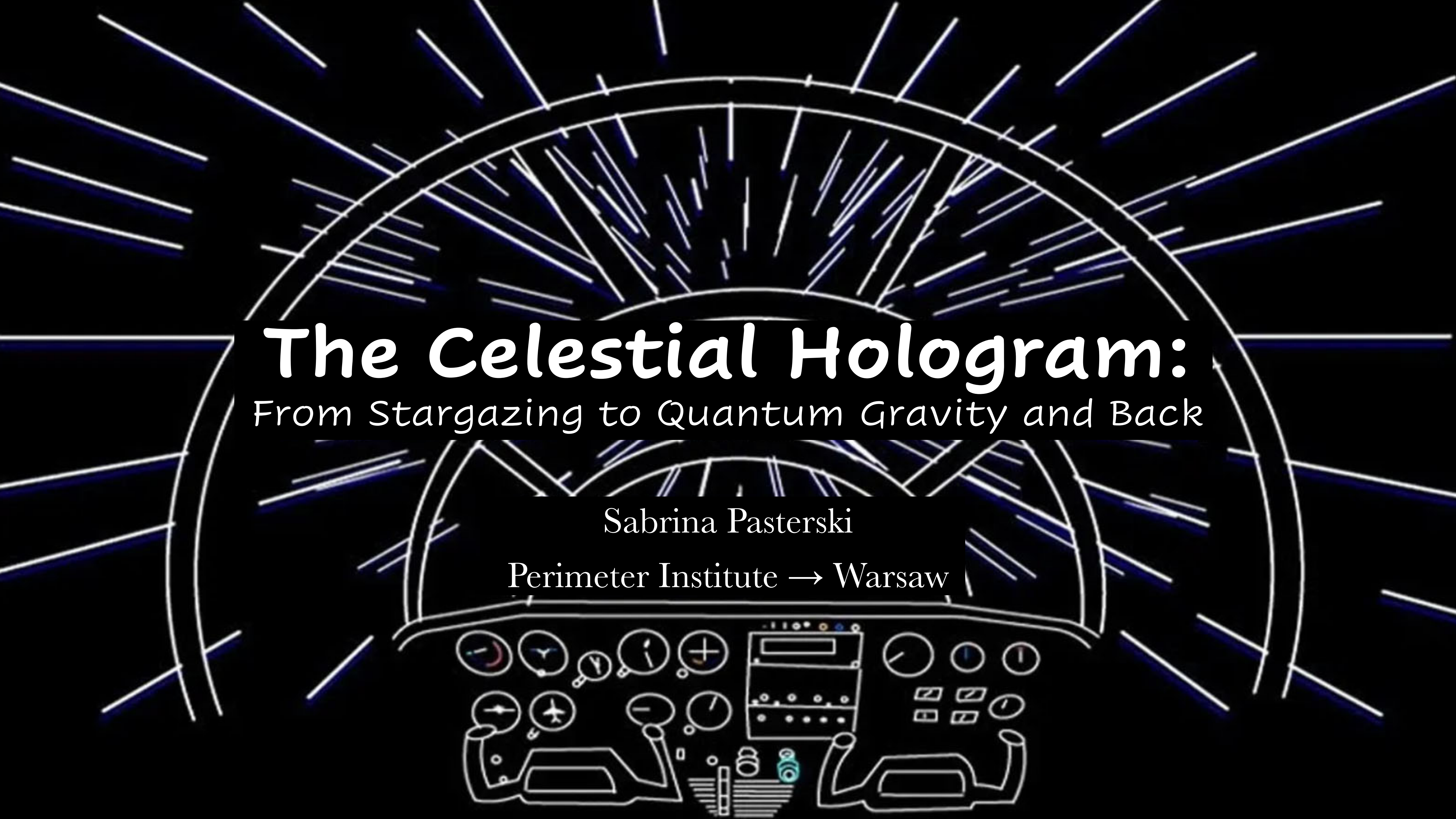
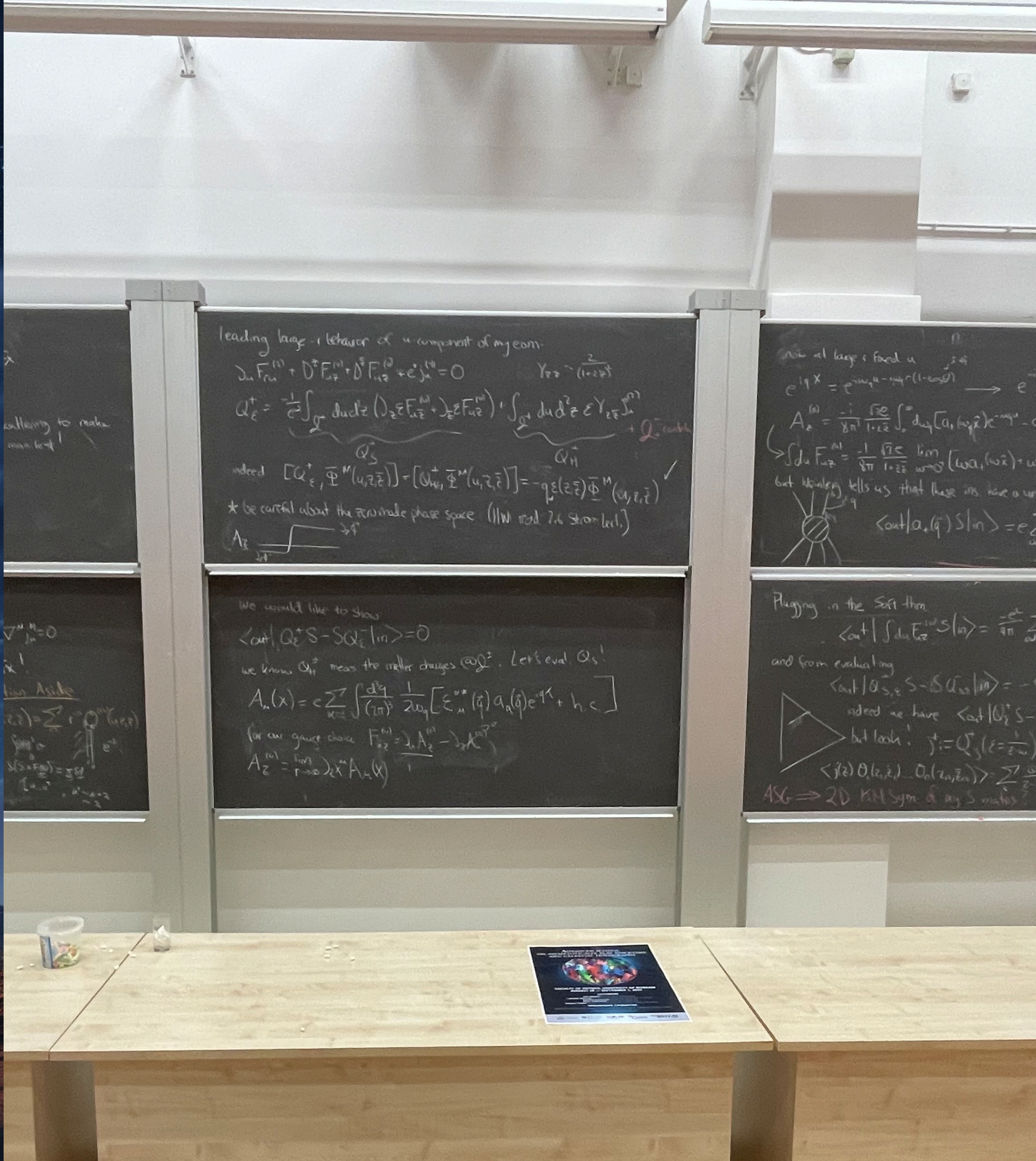


The Celestial Hologram:

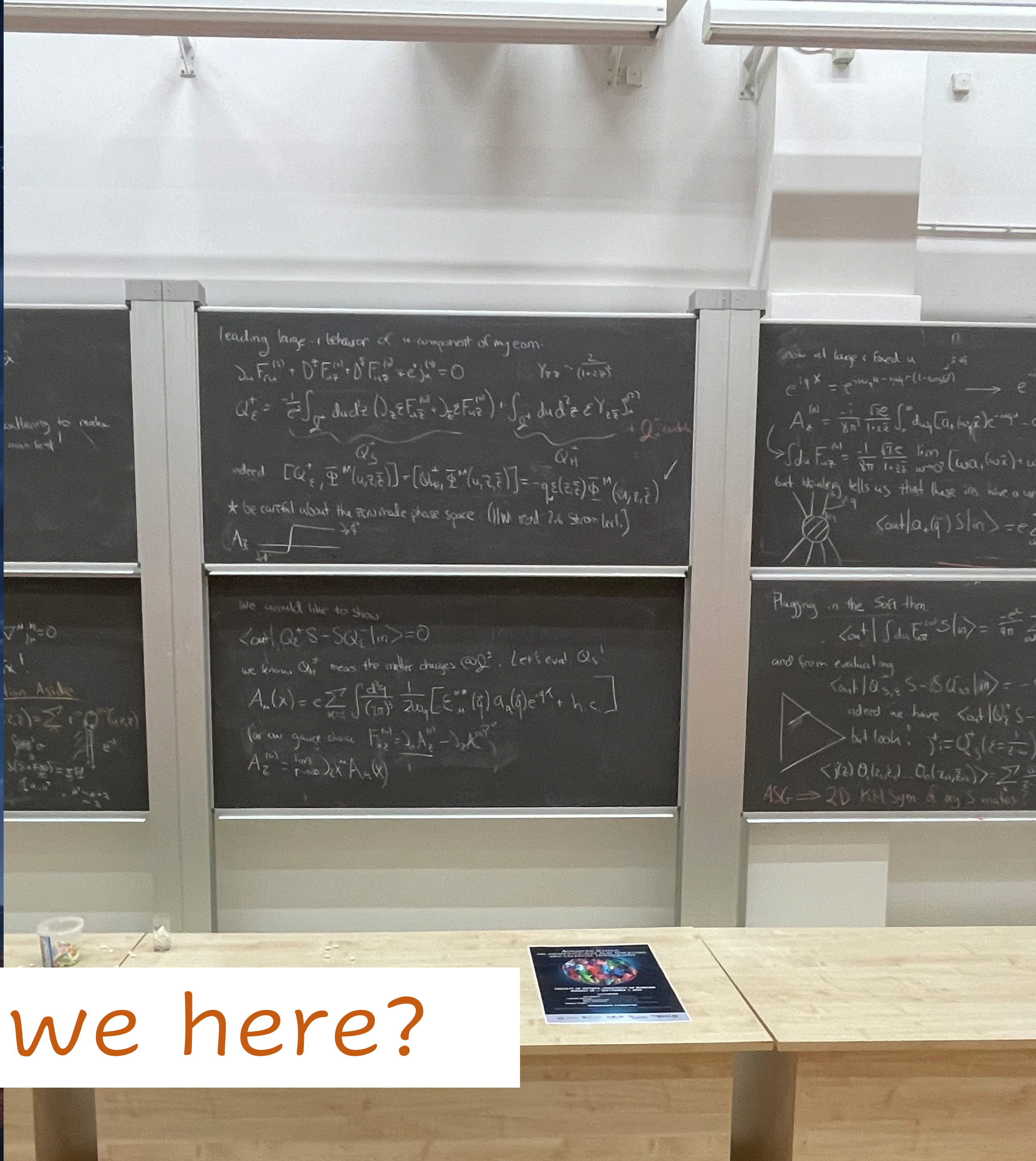
From Stargazing to Quantum Gravity and Back

Sabrina Pasterski

Perimeter Institute → Warsaw



We would like to show
Plugging in the Soft thm
and from evaluating



Why are we here?

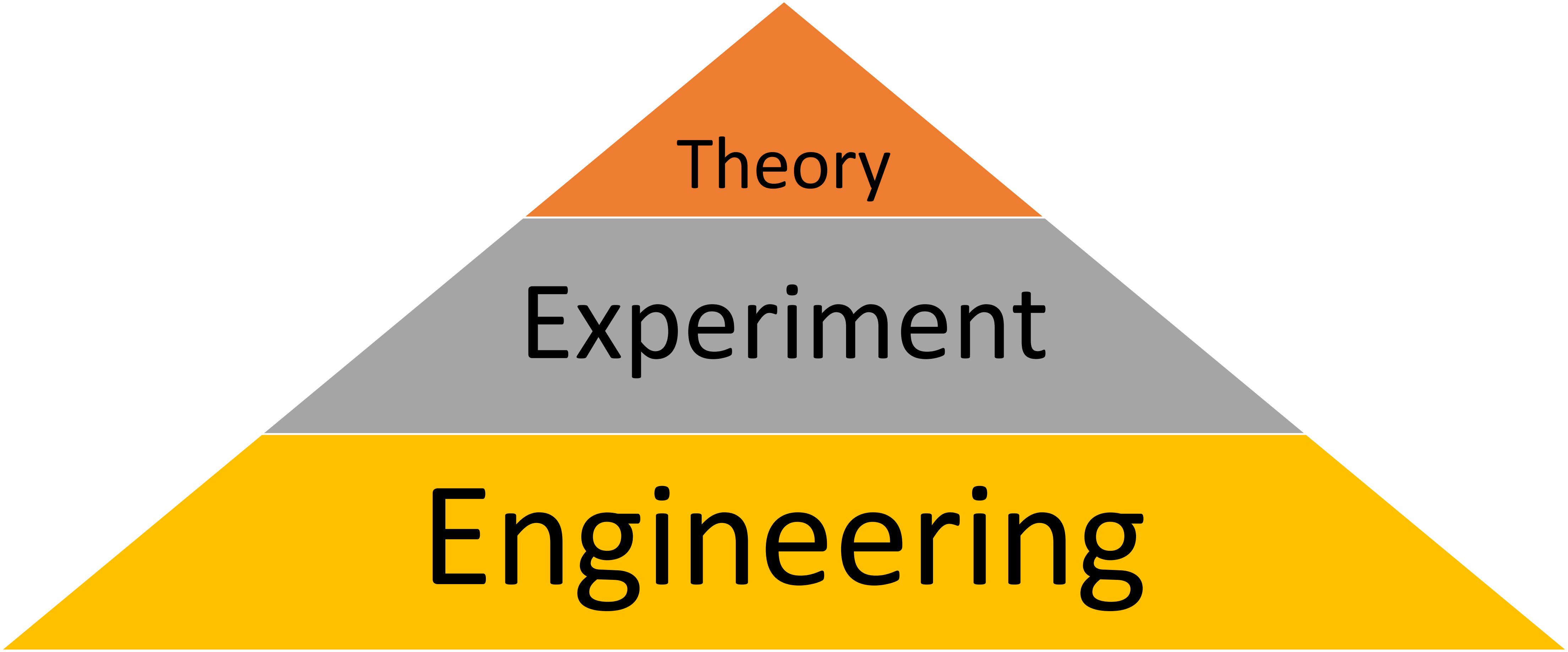
“Nothing in life is to be feared, it is only to be understood.”

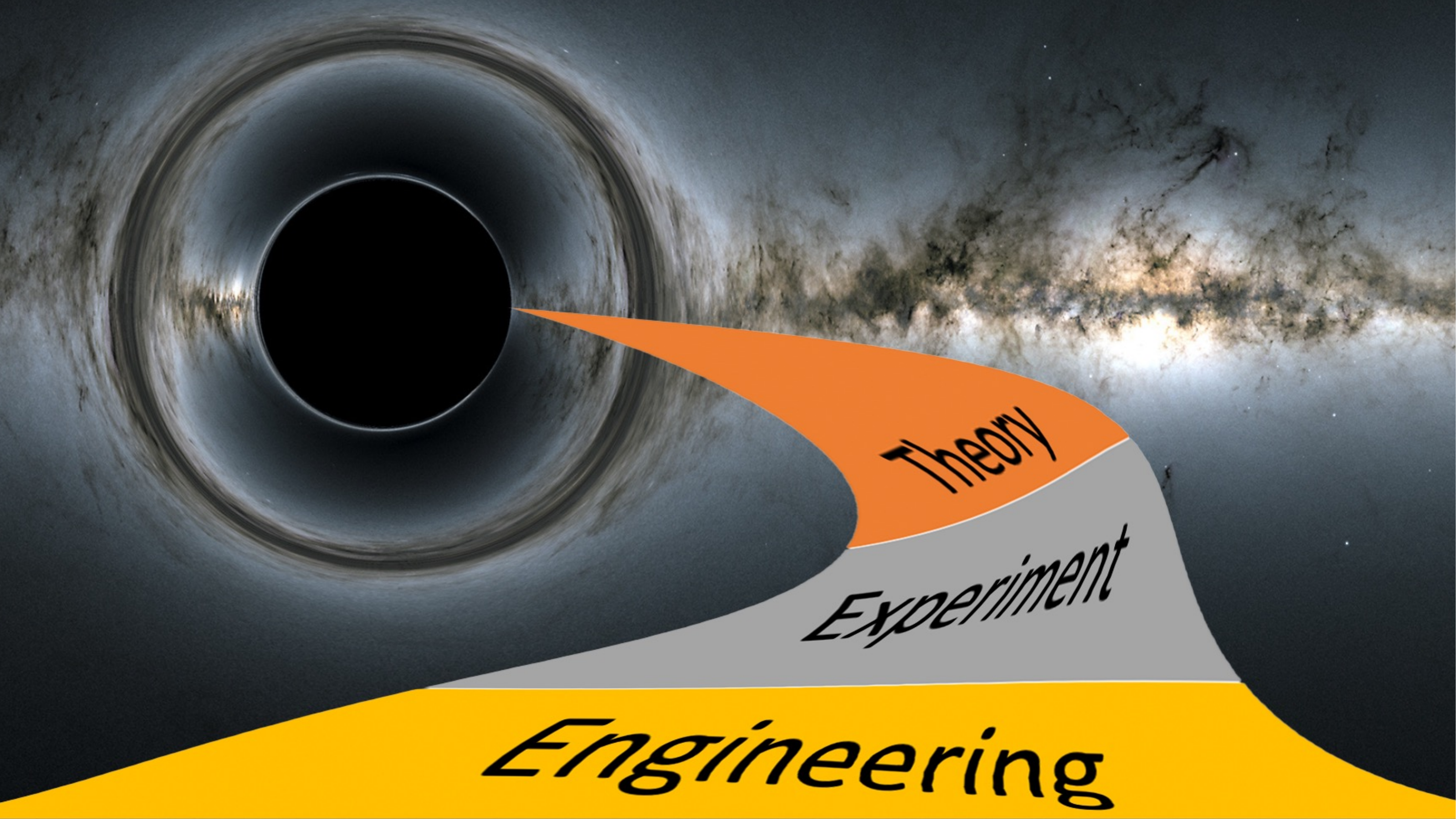
– Maria Skłodowska-Curie

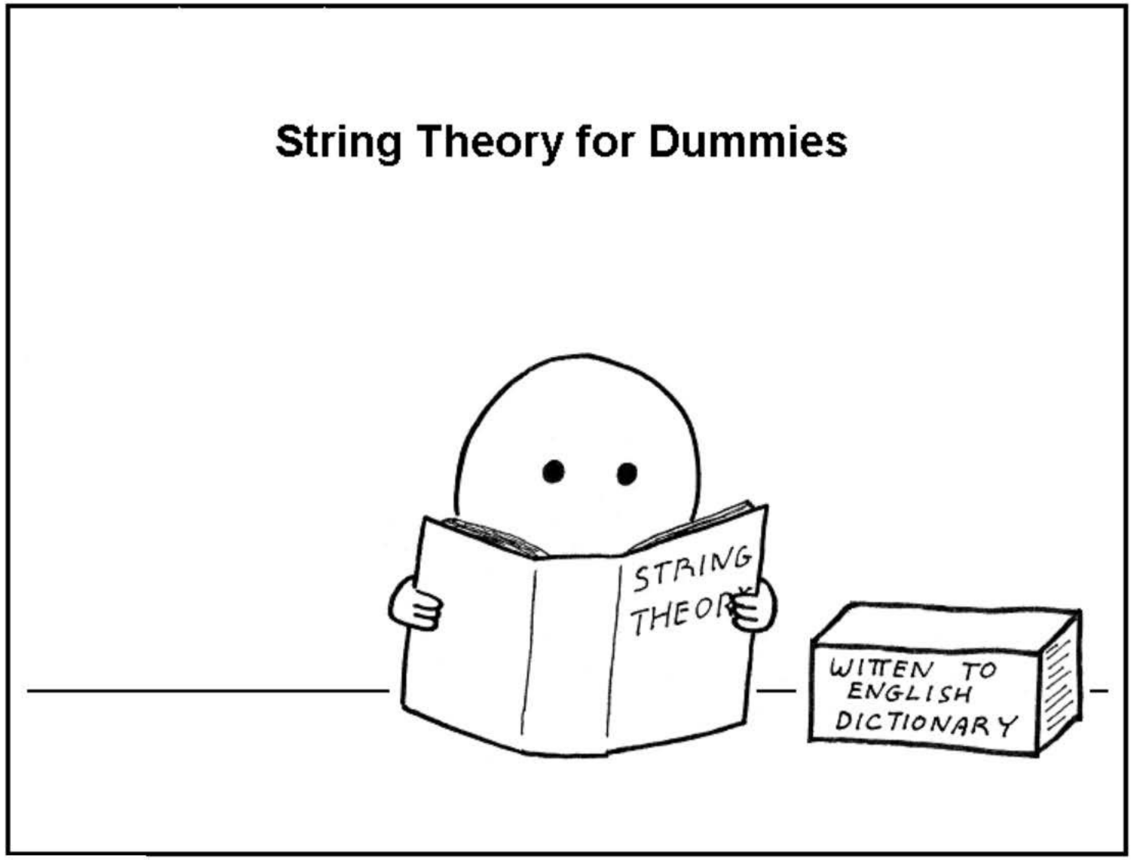
What are the fundamental laws obeyed by nature?

What happens at energy scales we can't (yet) probe?

What happens when you fall into a black hole?


Theory
Experiment
Engineering

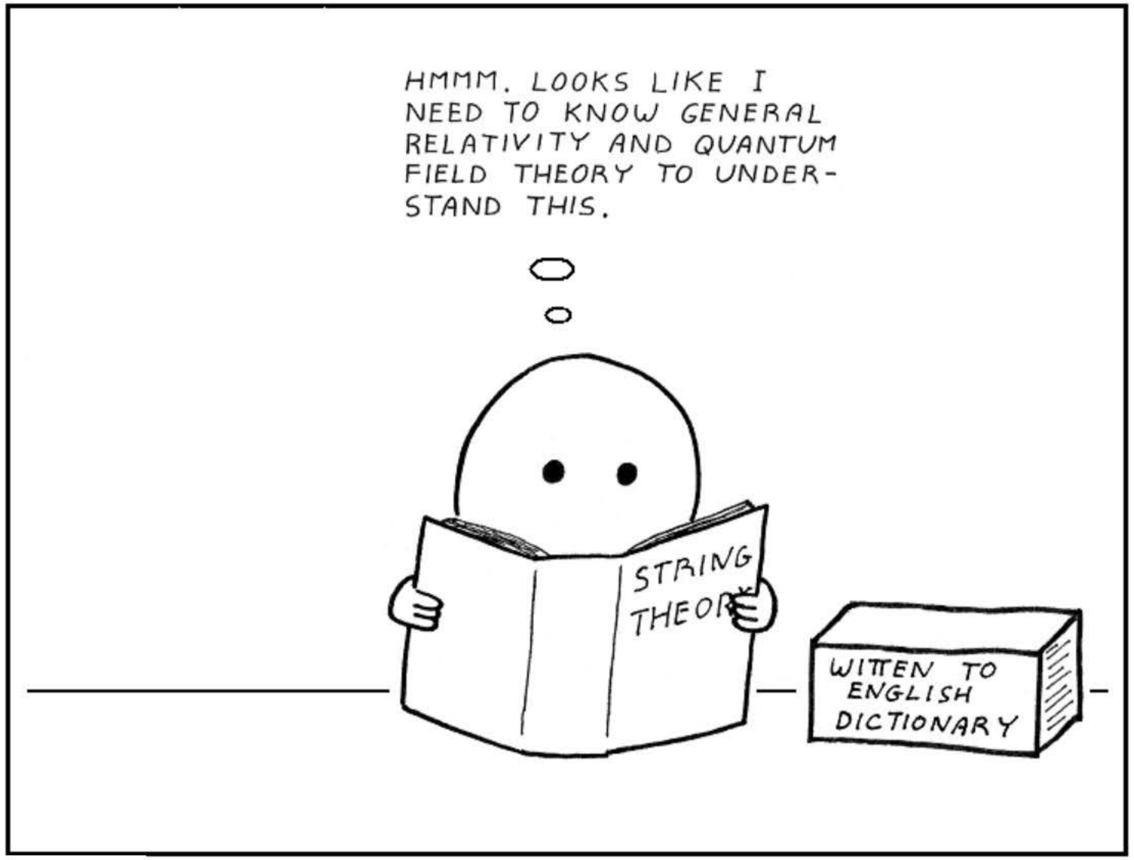

Theory
Experiment
Engineering



Abstruse Goose

STEP 1: begin

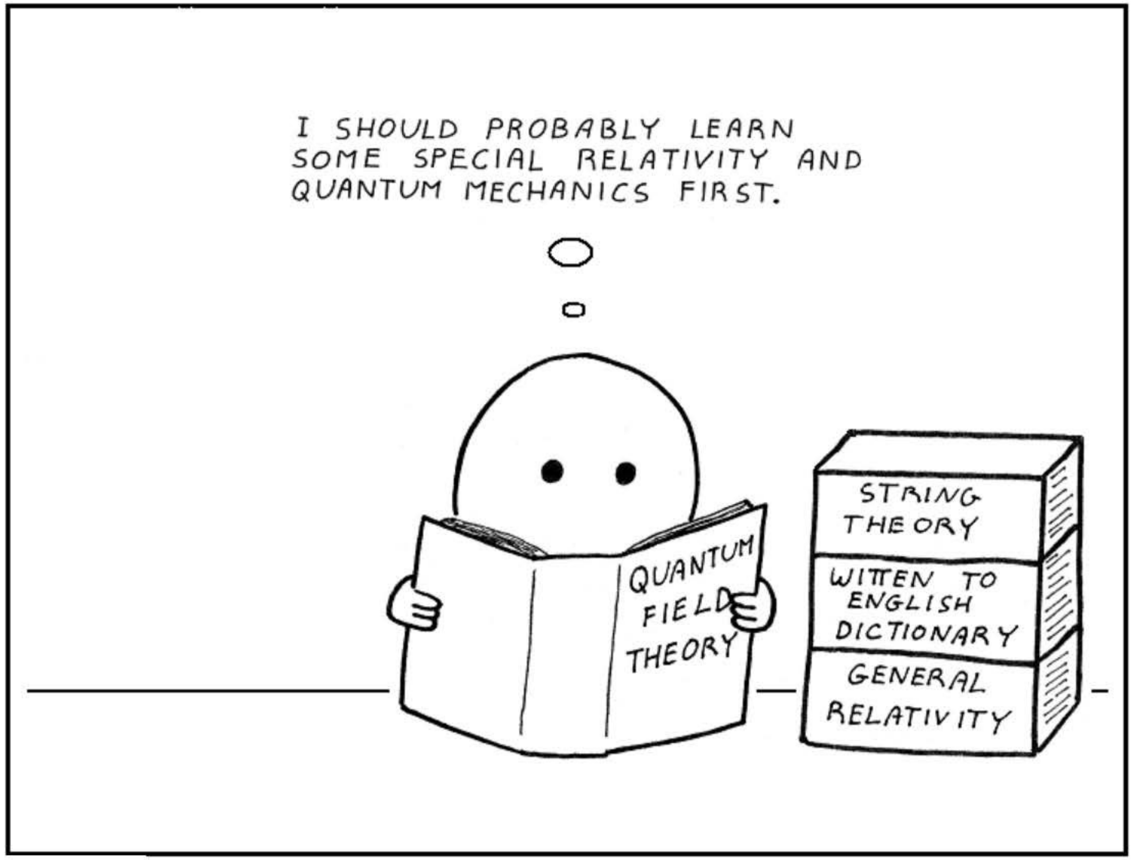
全玄鴻



Abstruse Goose

STEP 2: enter the rabbit hole

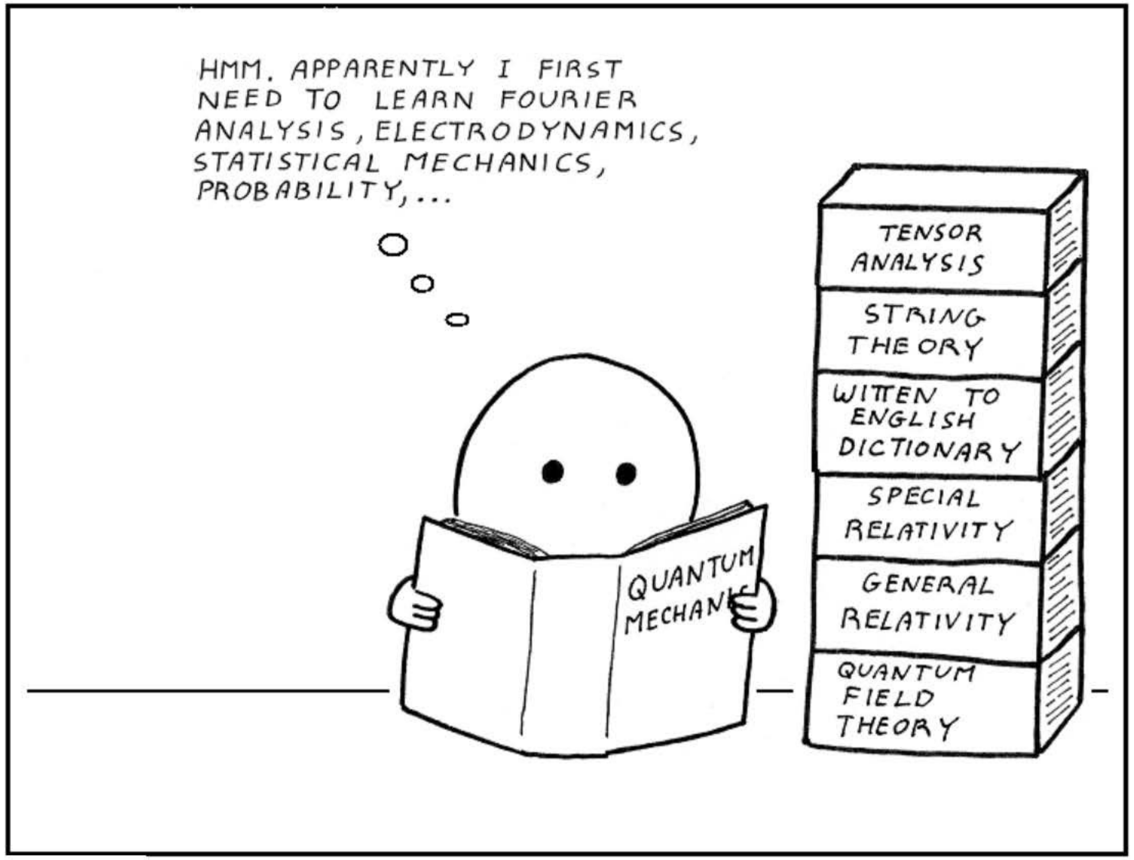
全玄鴻



Abstruse Goose

STEP 3: further down the rabbit hole

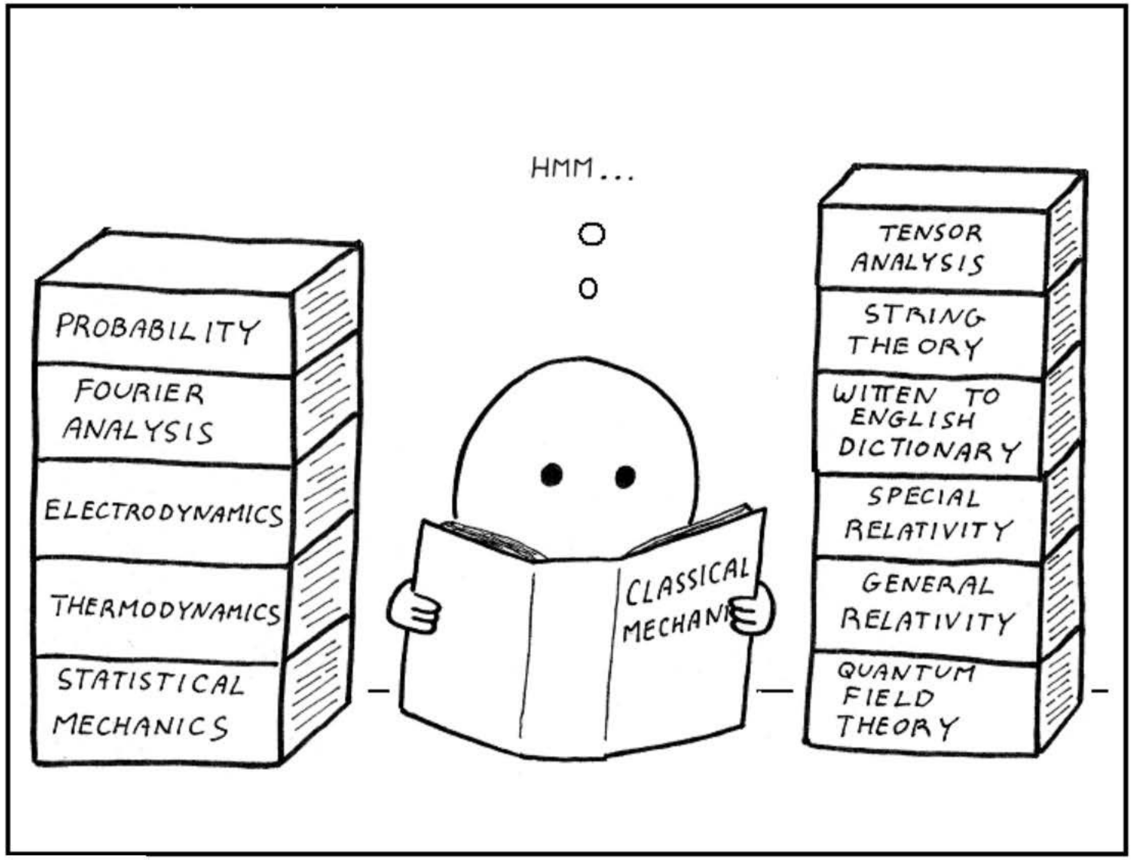
全玄鴻



Abstruse Goose

STEP 4: gradual realization

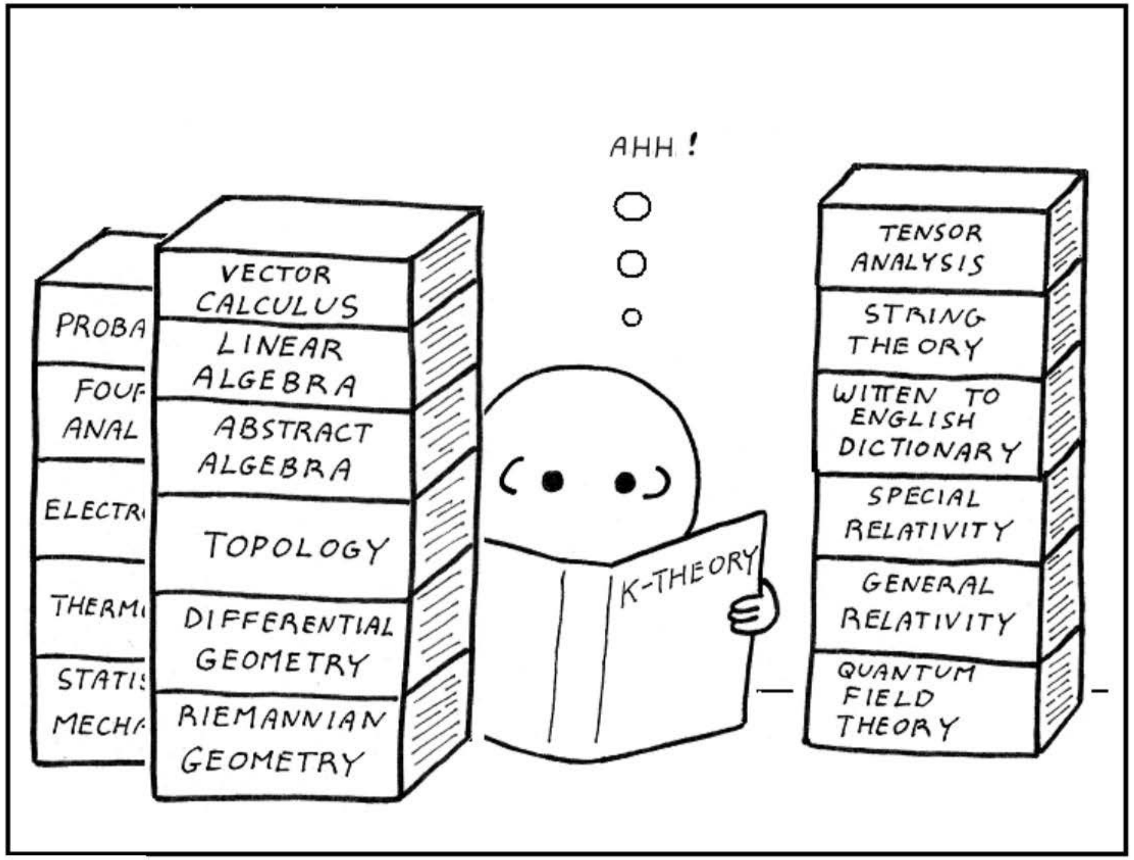
全玄鴻



Abstruse Goose

STEP 5: shock and awe

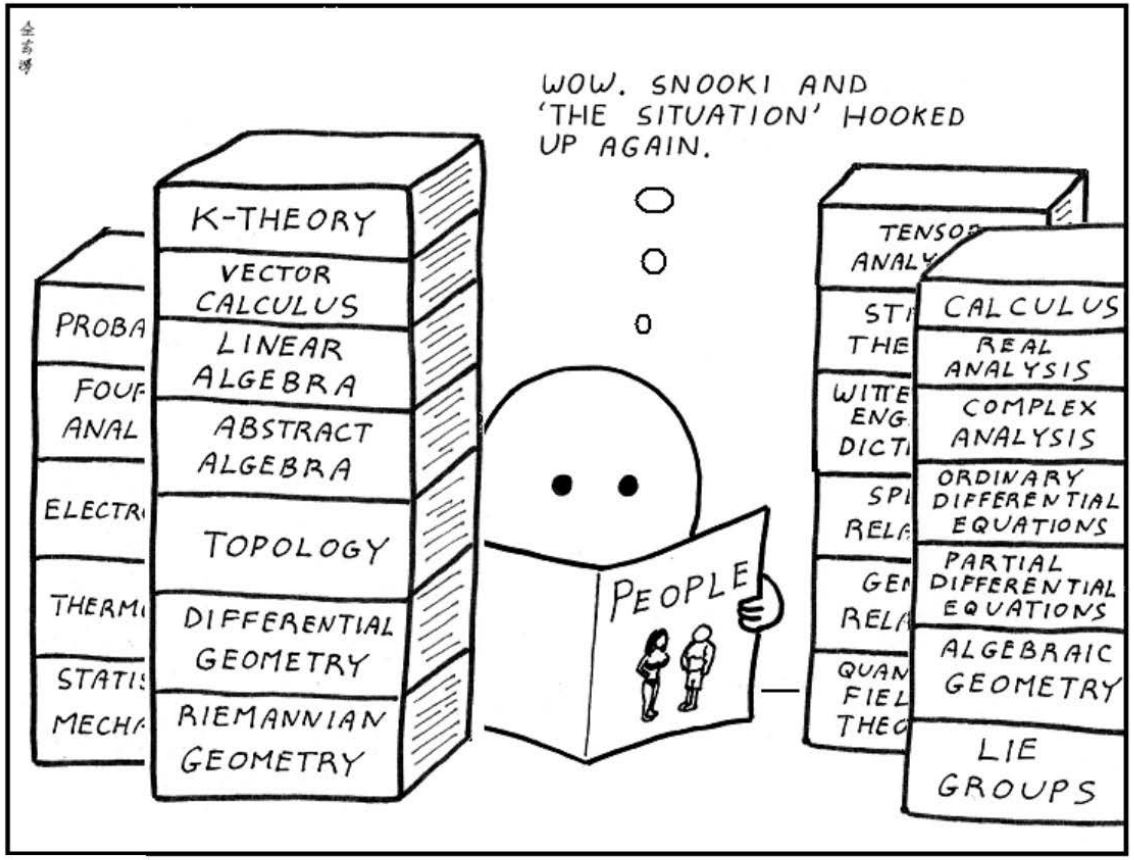
全玄鴻



Abstruse Goose

STEP 6: frustration

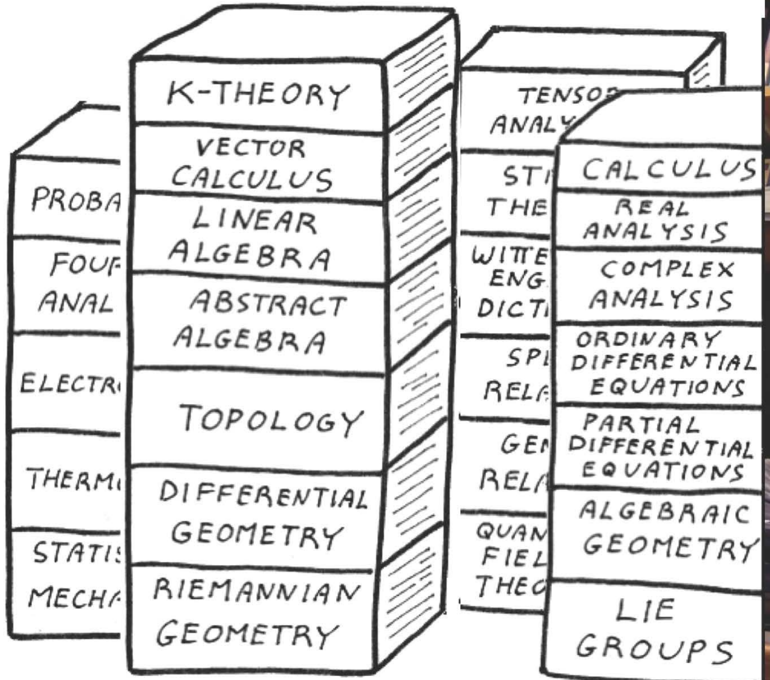
全玄鴻

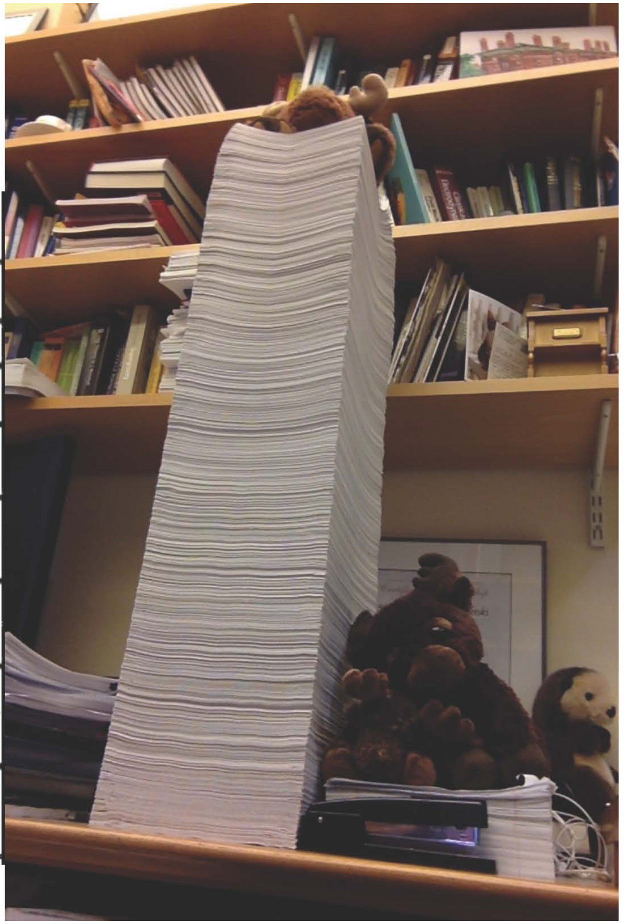


Abstruse Goose

STEP 7: capitulation

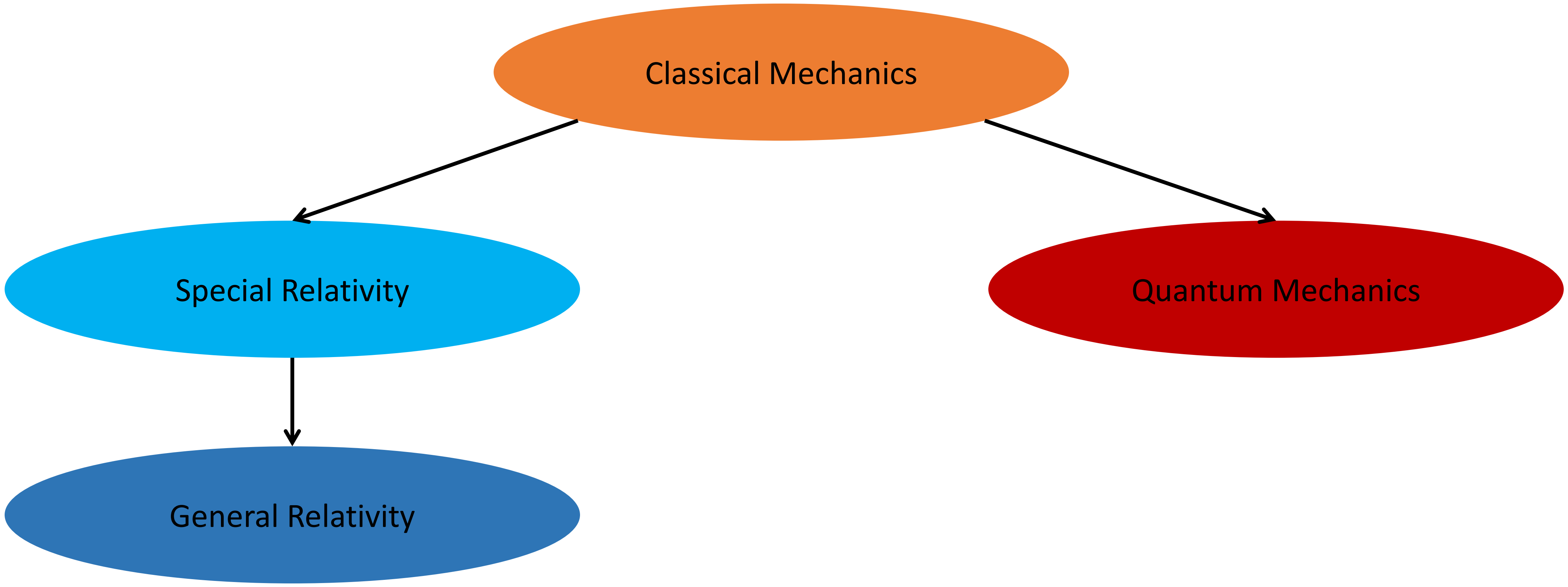
全玄鴻


K-THEORY
VECTOR CALCULUS
LINEAR ALGEBRA
ABSTRACT ALGEBRA
TOPOLOGY
DIFFERENTIAL GEOMETRY
RIEMANNIAN GEOMETRY
CALCULUS
REAL ANALYSIS
COMPLEX ANALYSIS
ORDINARY DIFFERENTIAL EQUATIONS
PARTIAL DIFFERENTIAL EQUATIONS
ALGEBRAIC GEOMETRY
LIE GROUPS

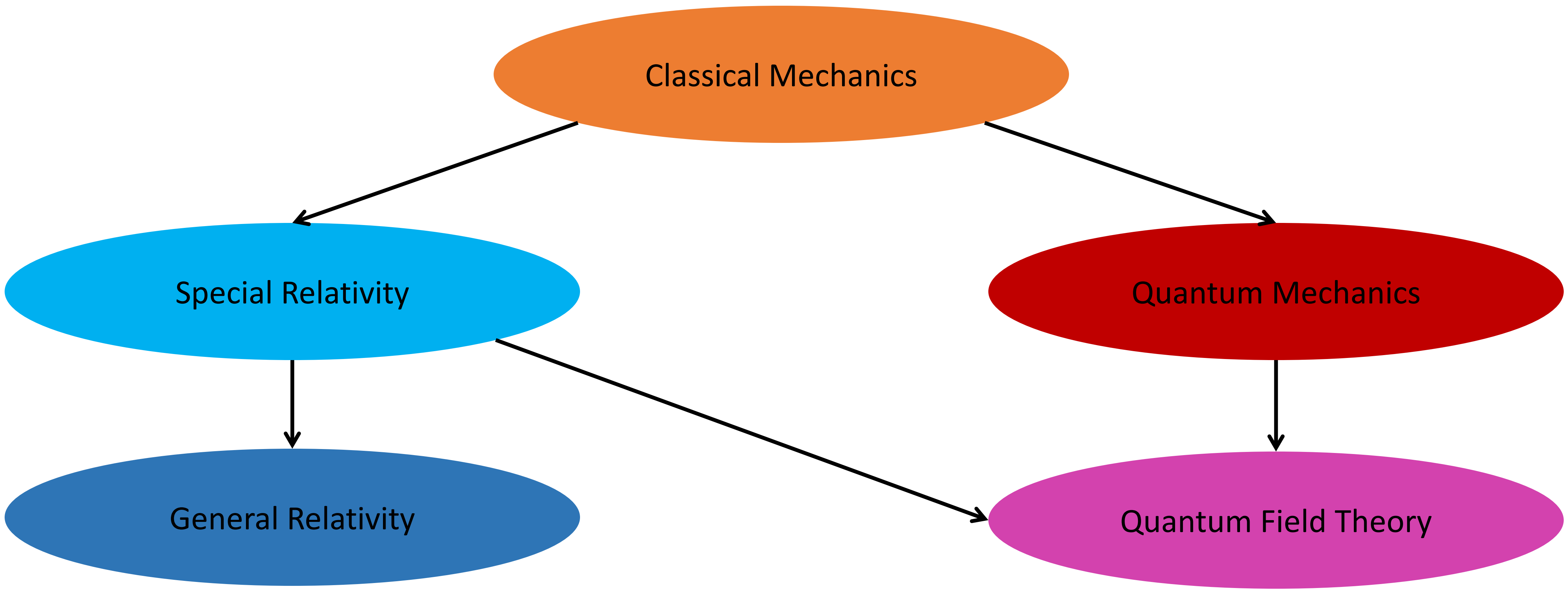


"If I have seen further, it is by standing on the shoulders of giants."

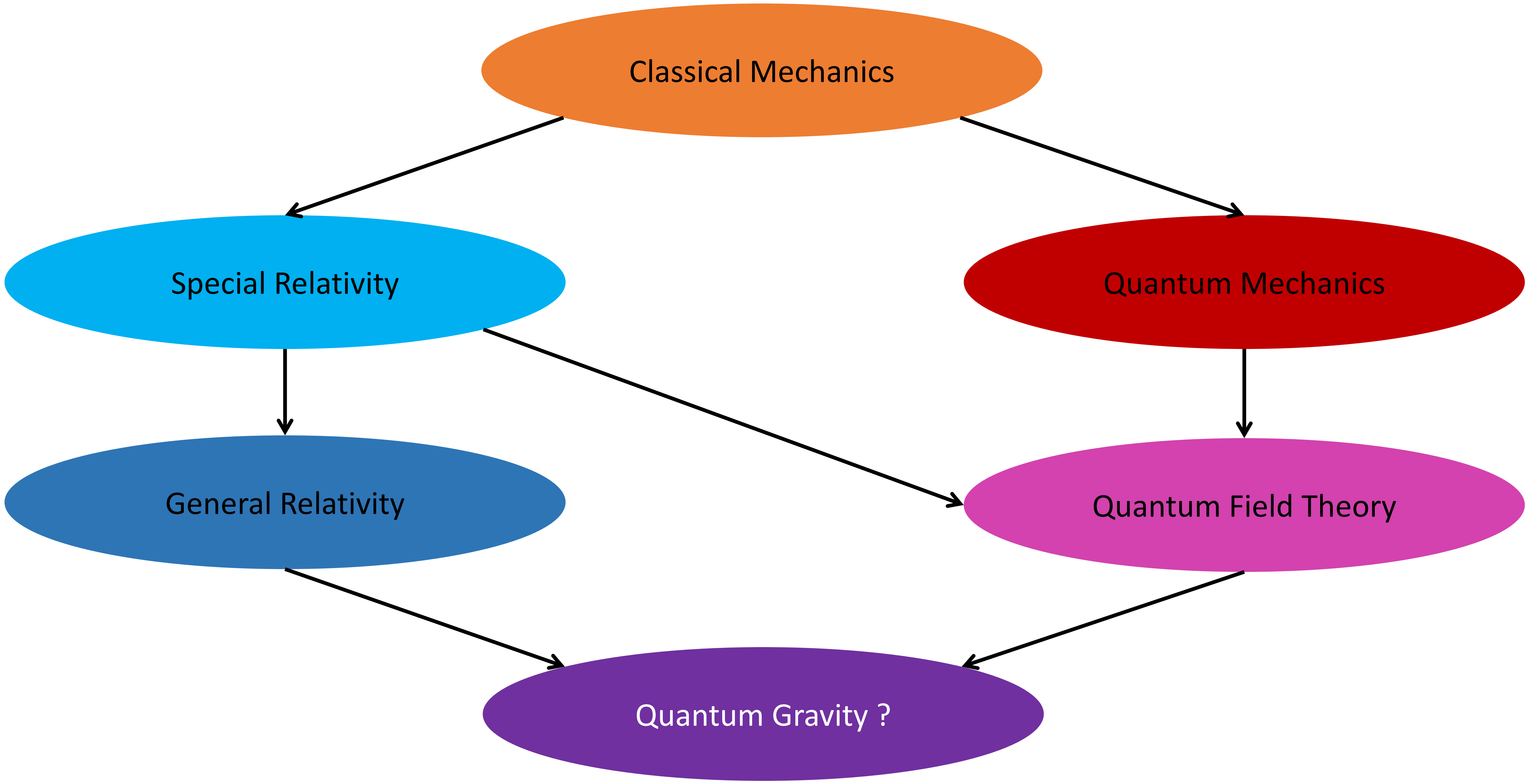
– Isaac Newton


Classical Mechanics
Special Relativity
Quantum Mechanics
General Relativity

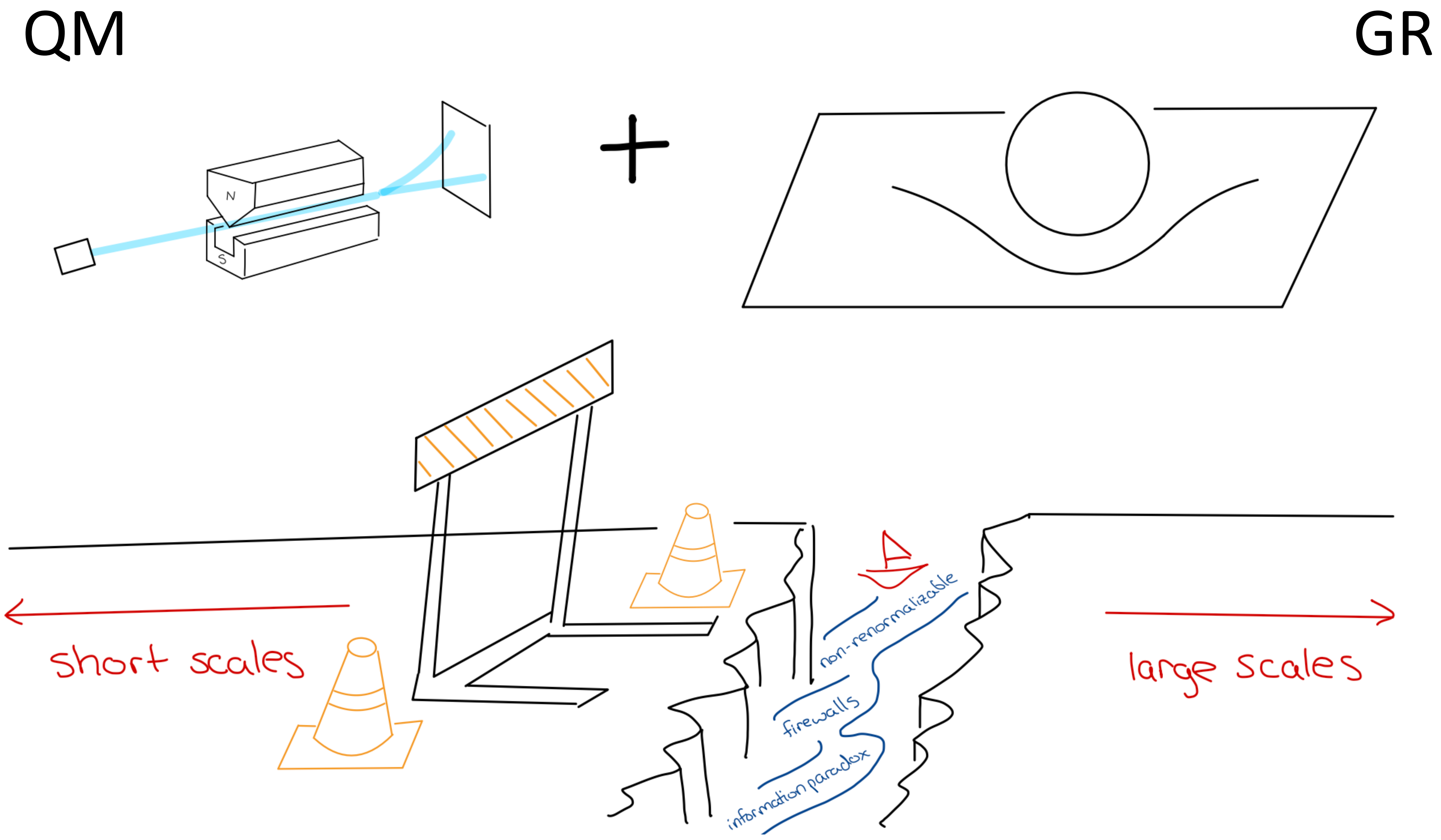
Early 1900s


Classical Mechanics
Special Relativity
Quantum Mechanics
General Relativity
Quantum Field Theory

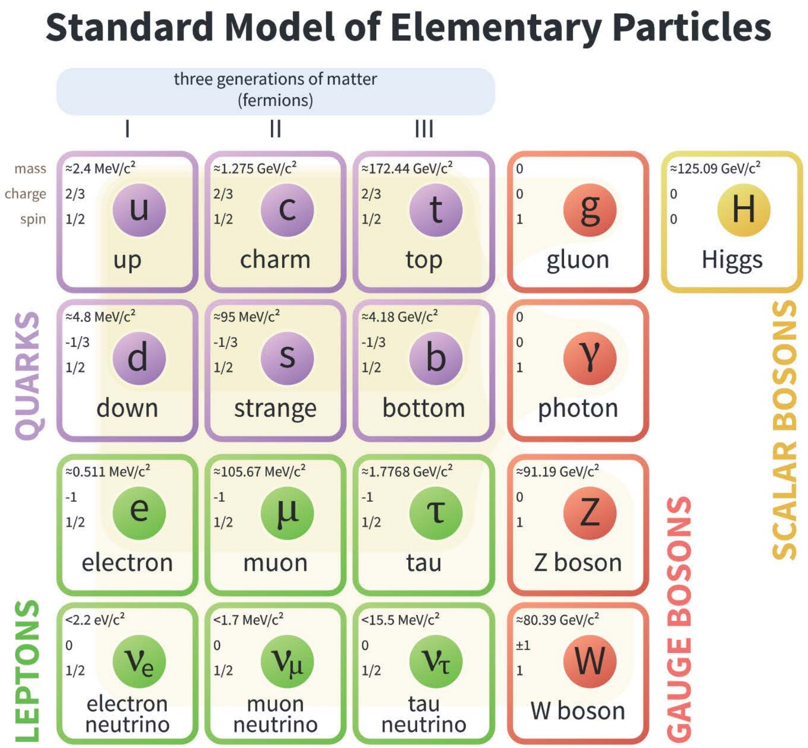
1930s-1970s

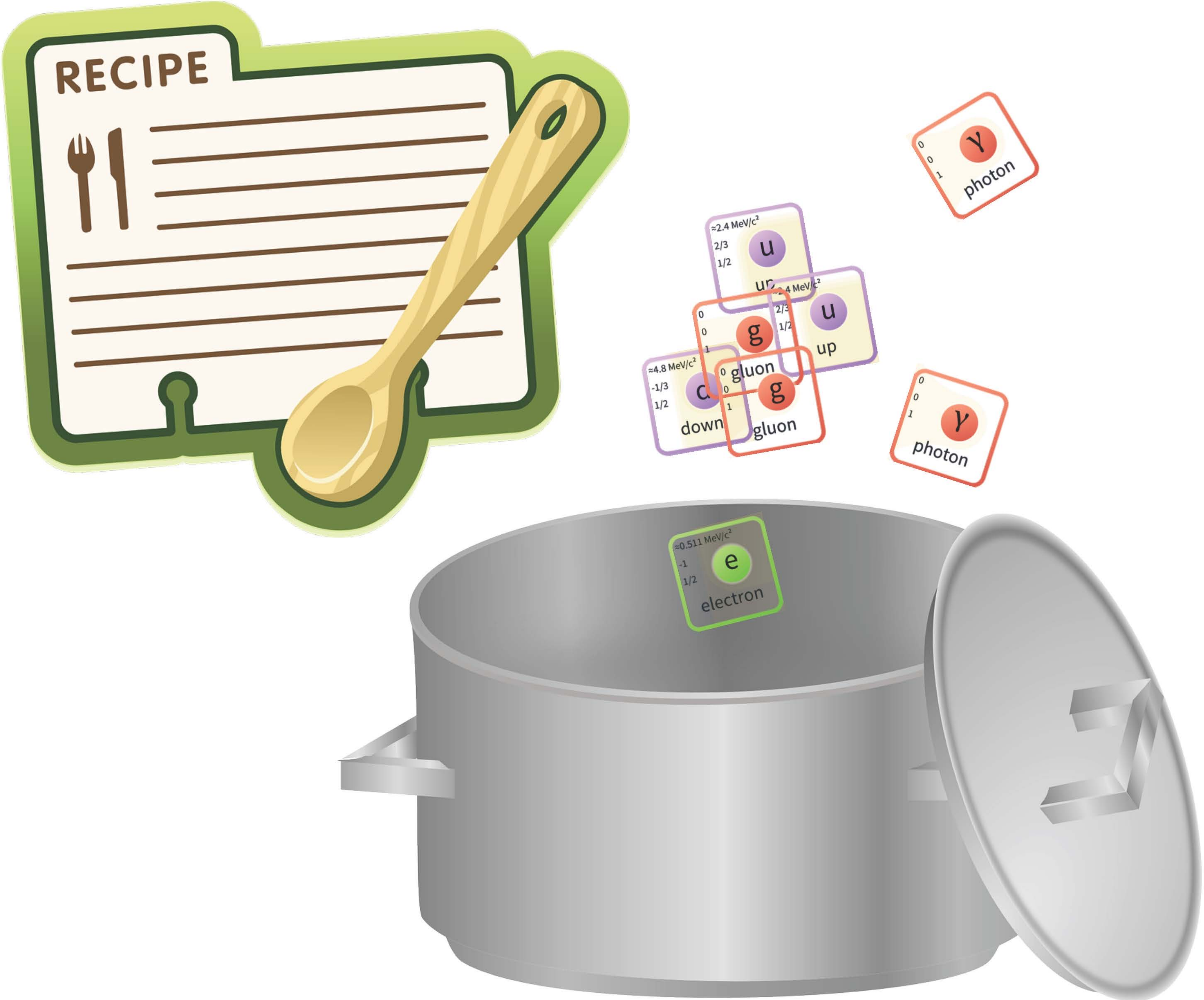


Juan's public talk at Strings 23

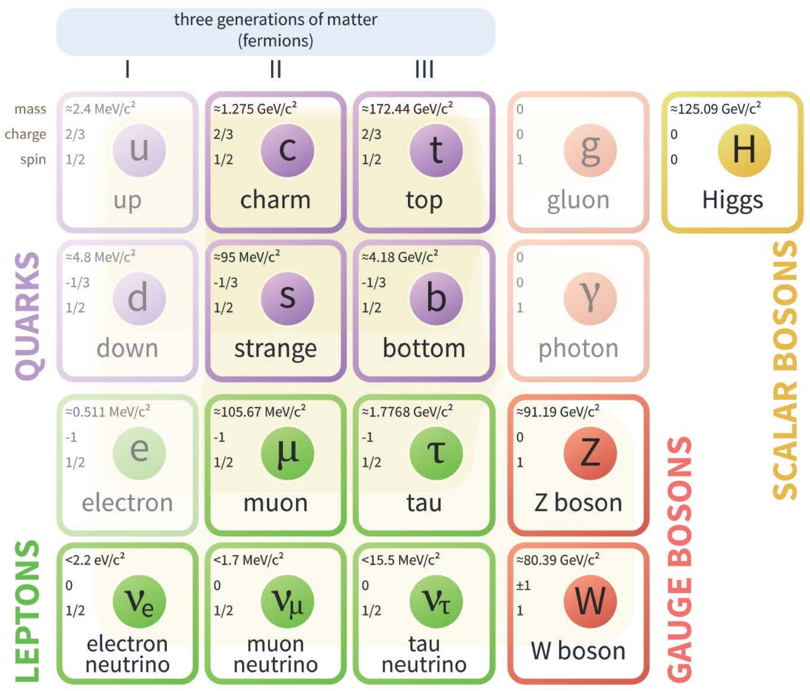

QM
GR
N
S
+
short scales
large scales
non-renormalizable
firewalls
information paradox

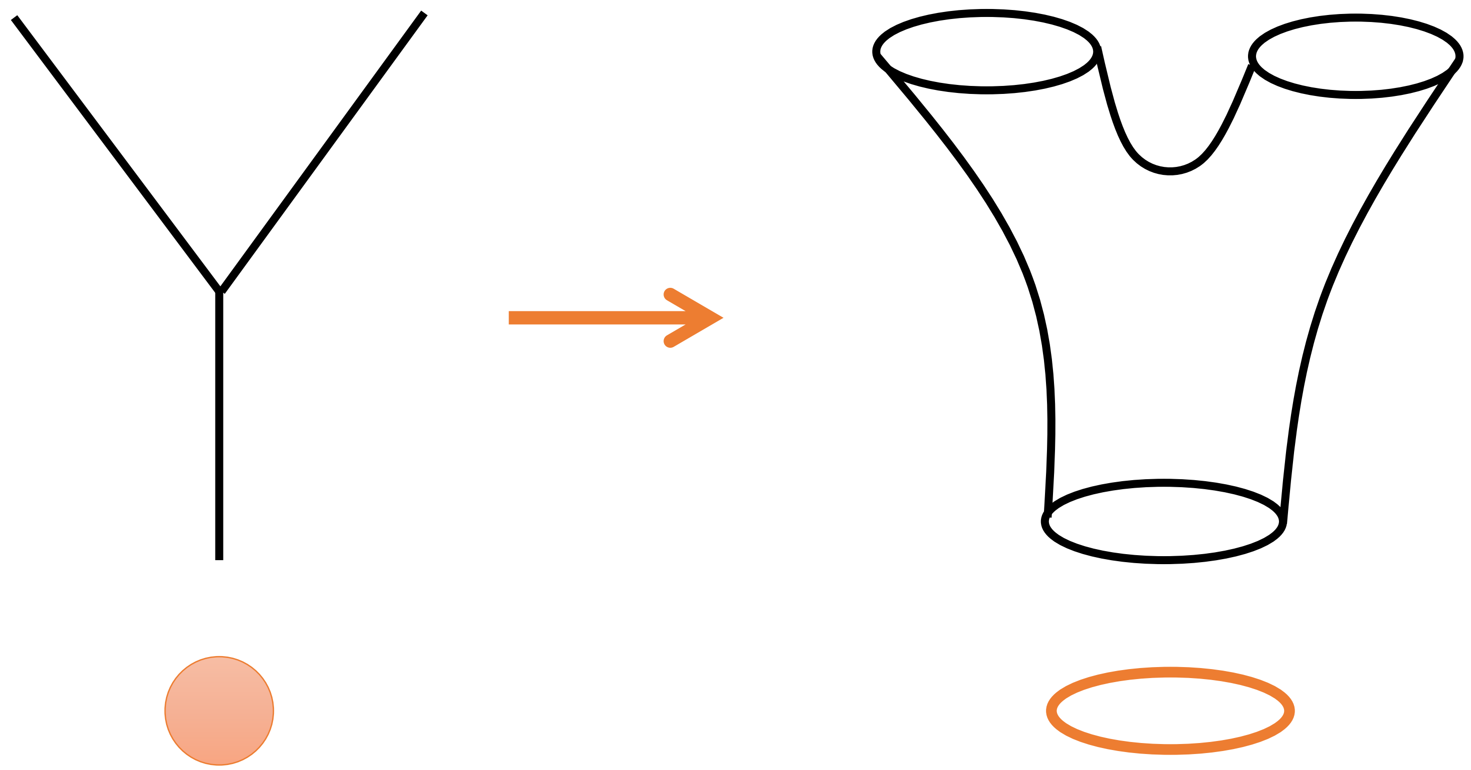

RECIPE

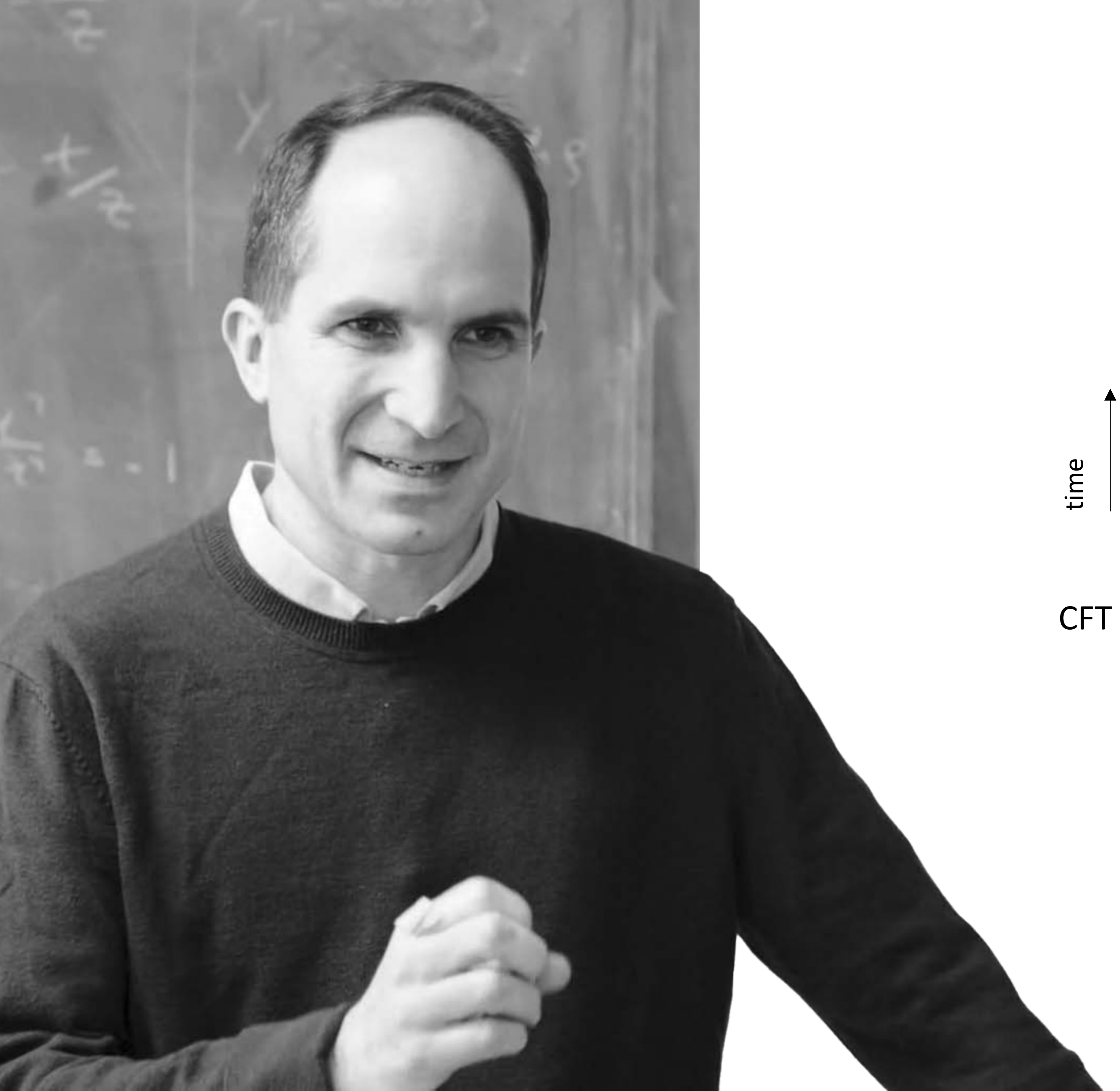

Standard Model of Elementary Particles
three generations of matter
(fermions)
I
II
III
mass
charge
spin
≈2.4 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈172.44 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈125.09 GeV/c²
0
0
H
Higgs
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
≈0.511 MeV/c²
-1
1/2
e
electron
≈105.67 MeV/c²
-1
1/2
μ
muon
≈1.7768 GeV/c²
-1
1/2
τ
tau
≈91.19 GeV/c²
0
1
Z
Z boson
<2.2 eV/c²
0
1/2
νe
electron neutrino
<1.7 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
≈80.39 GeV/c²
±1
1
W
W boson
QUARKS
LEPTONS
GAUGE BOSONS
SCALAR BOSONS

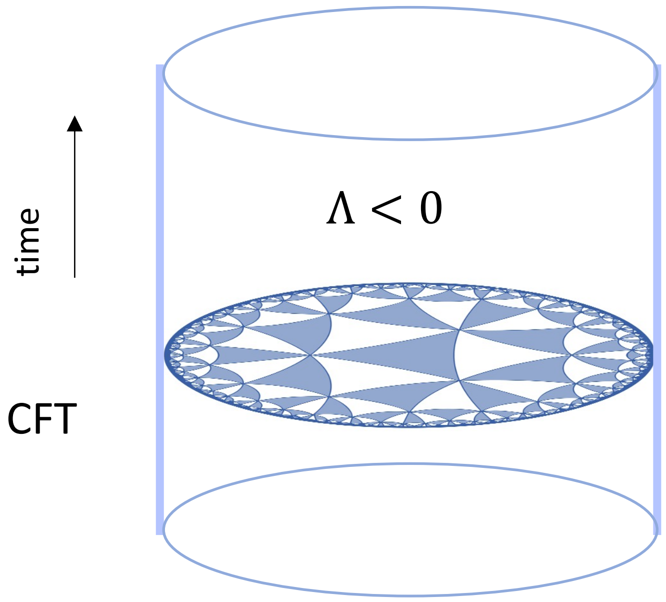


Standard Model of Elementary Particles

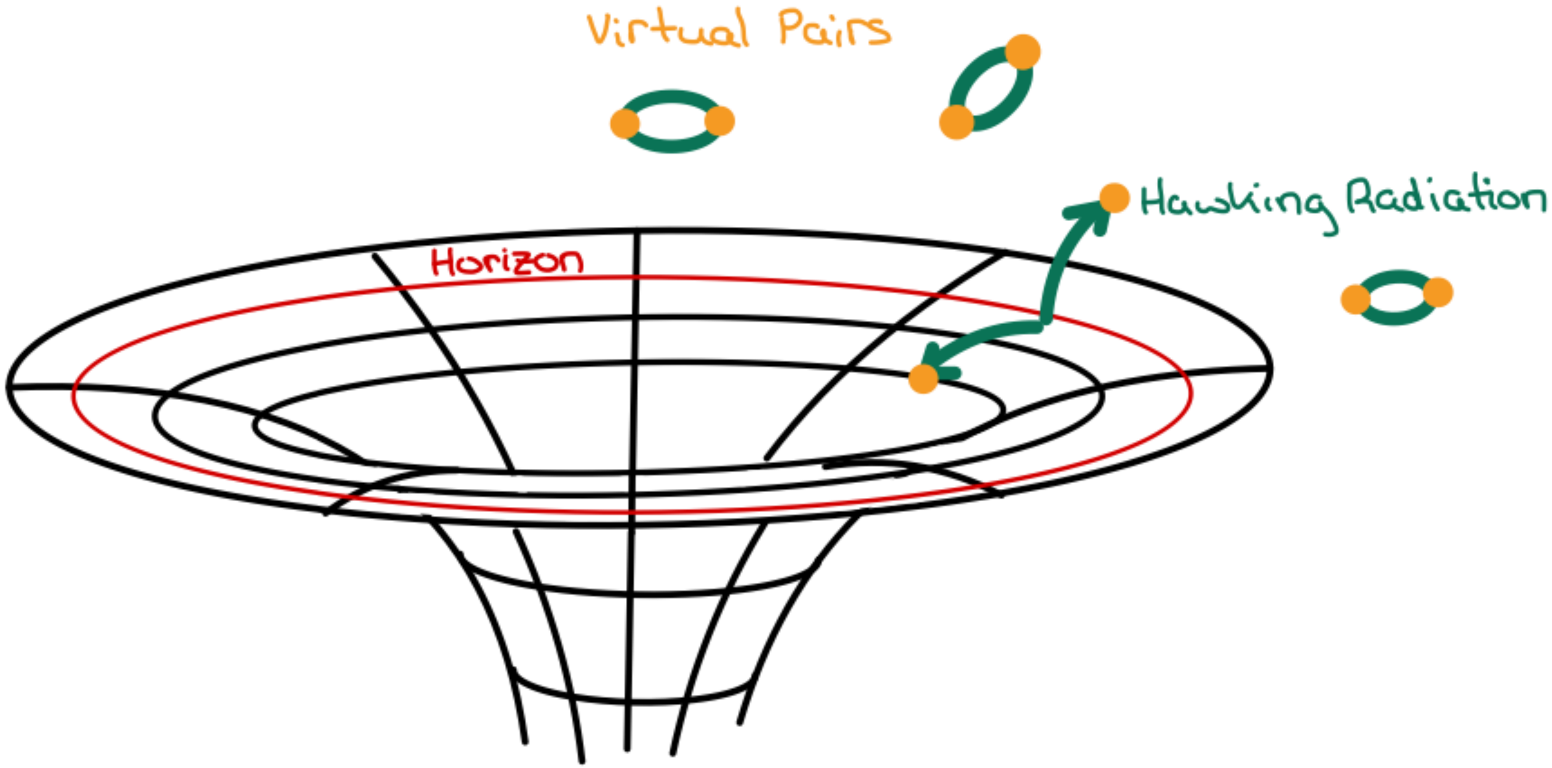


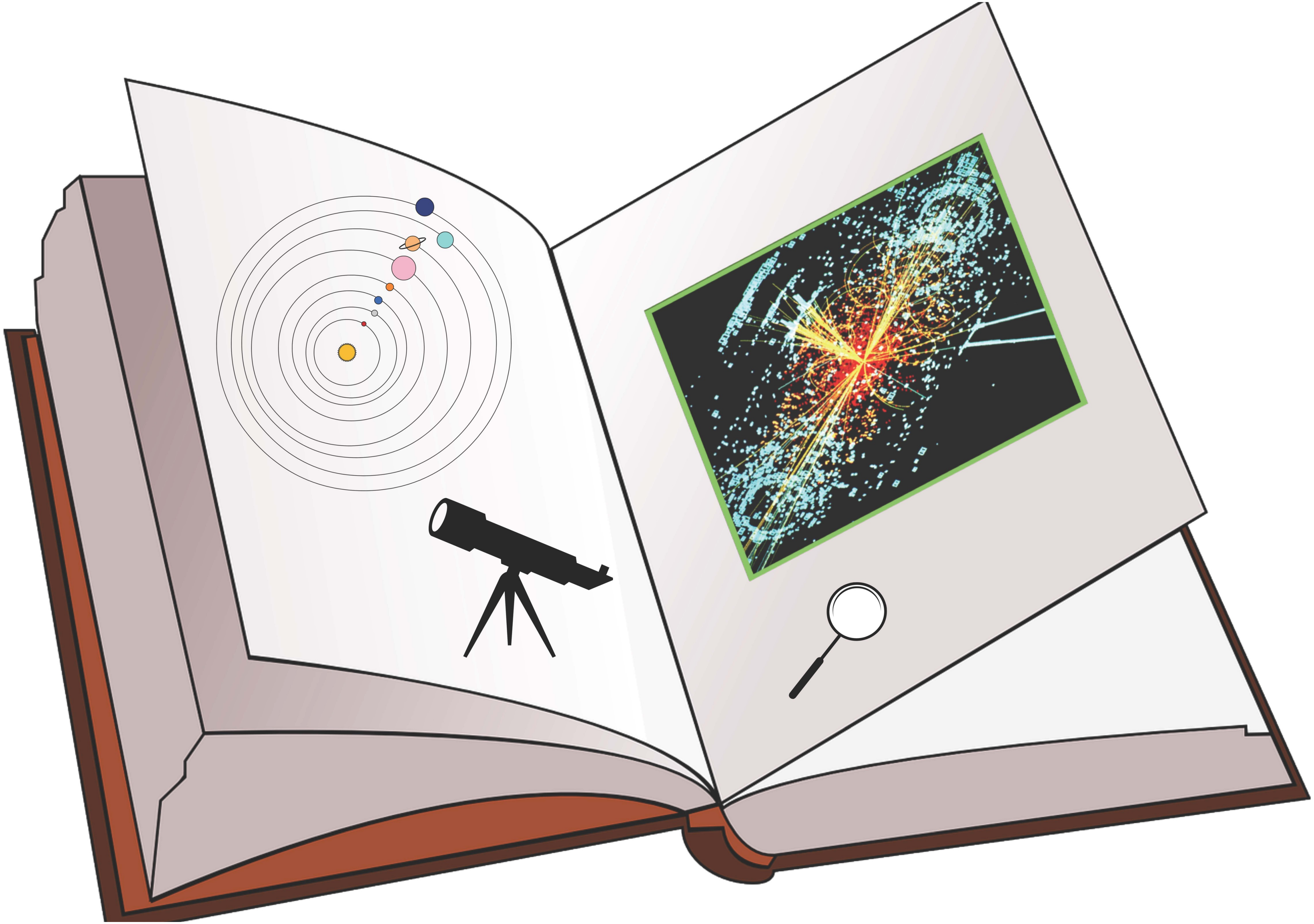


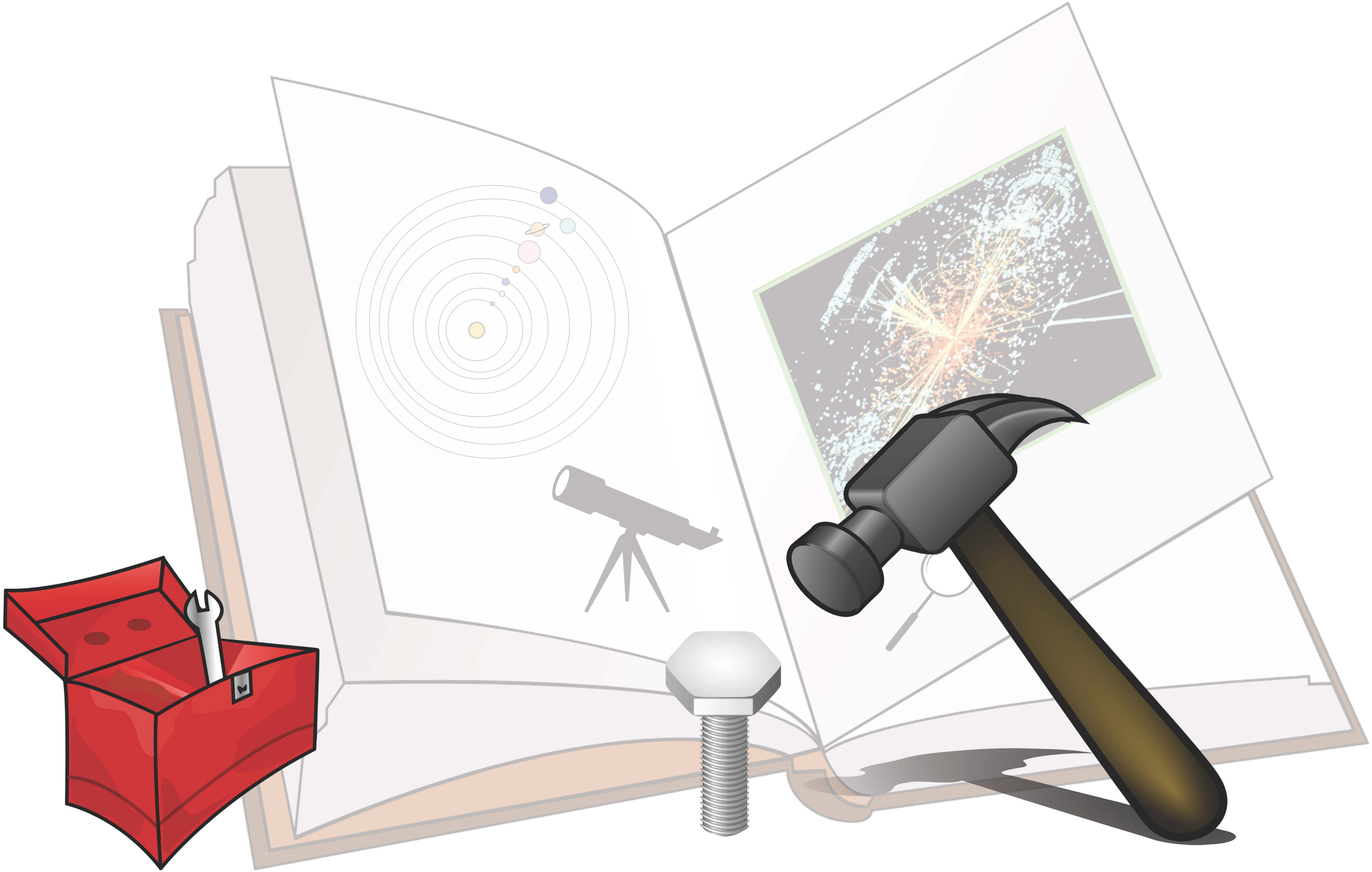


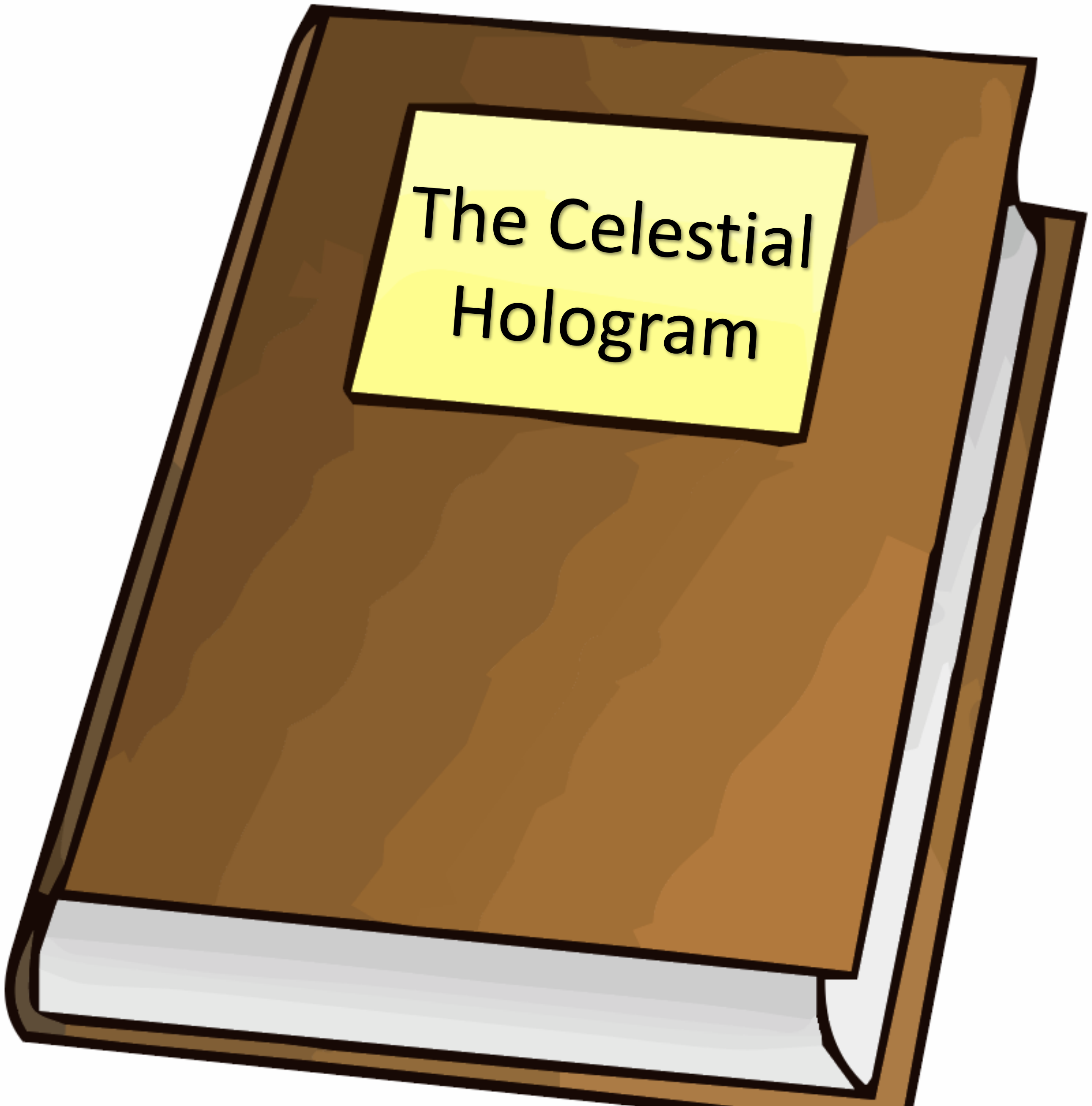

time
$\Lambda < 0$
CFT

$$S_{BH} = \frac{c^3 Area_{Horizon}}{4 G_N \hbar}$$

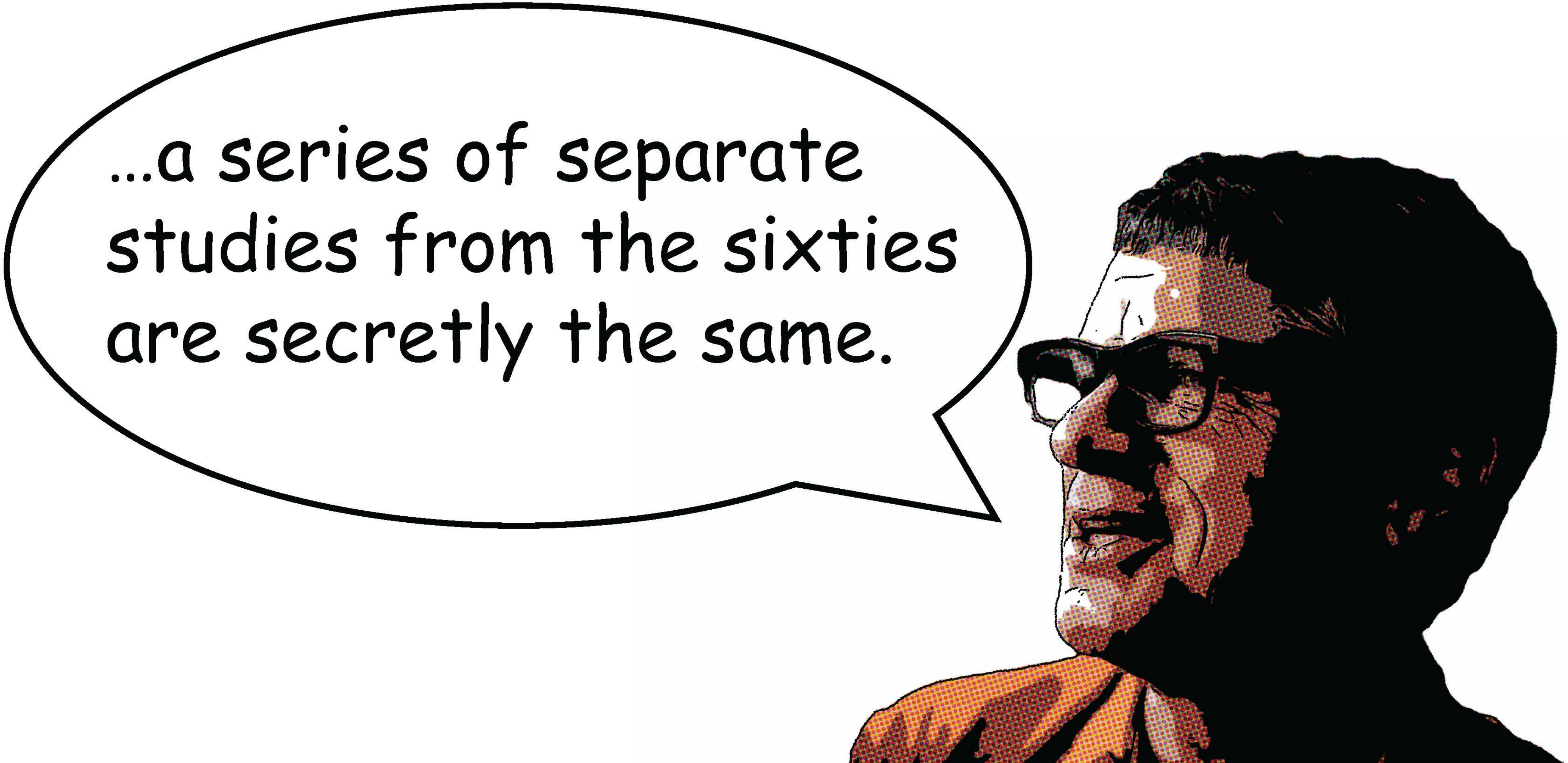


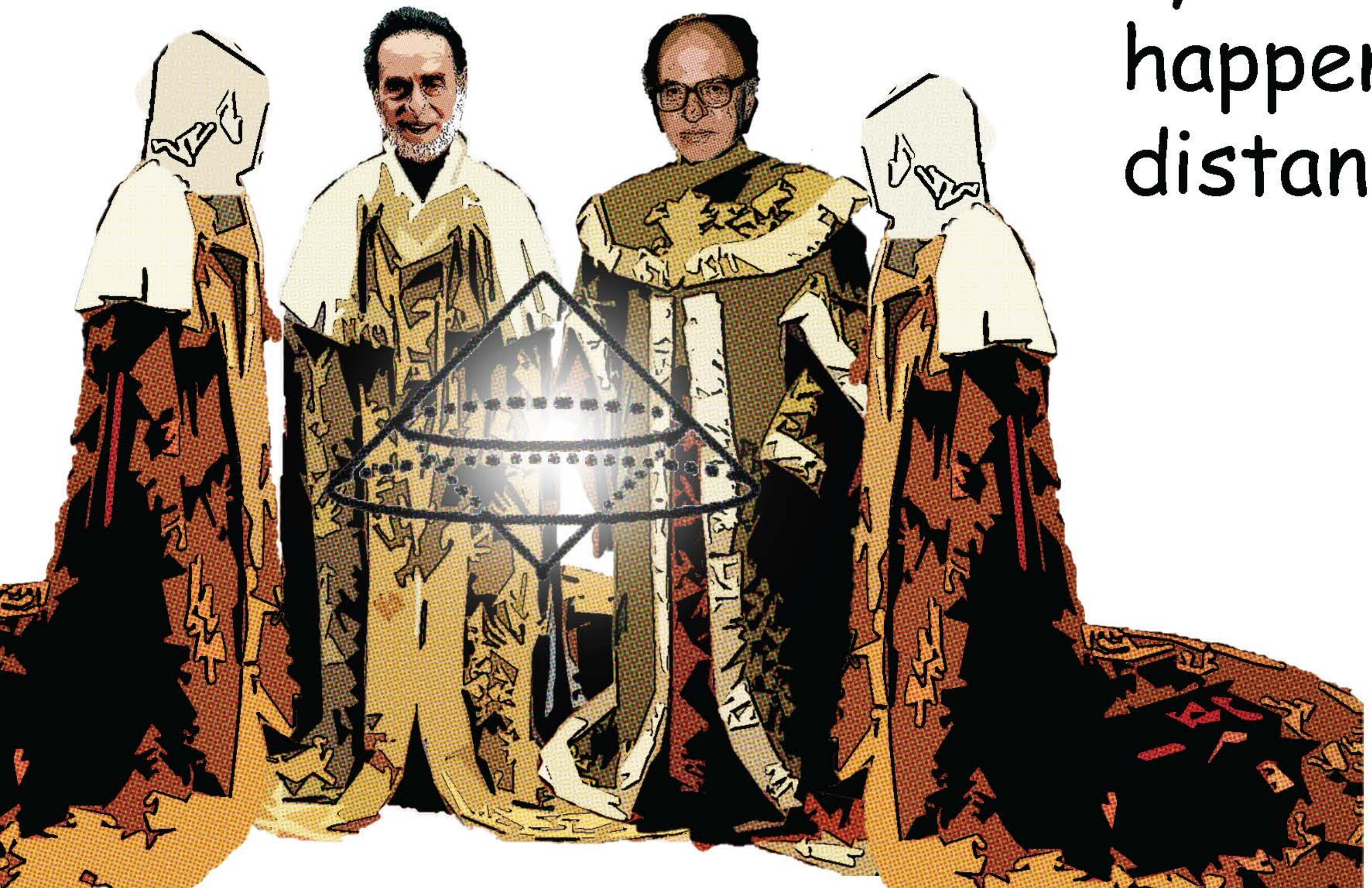





The Celestial
Hologram

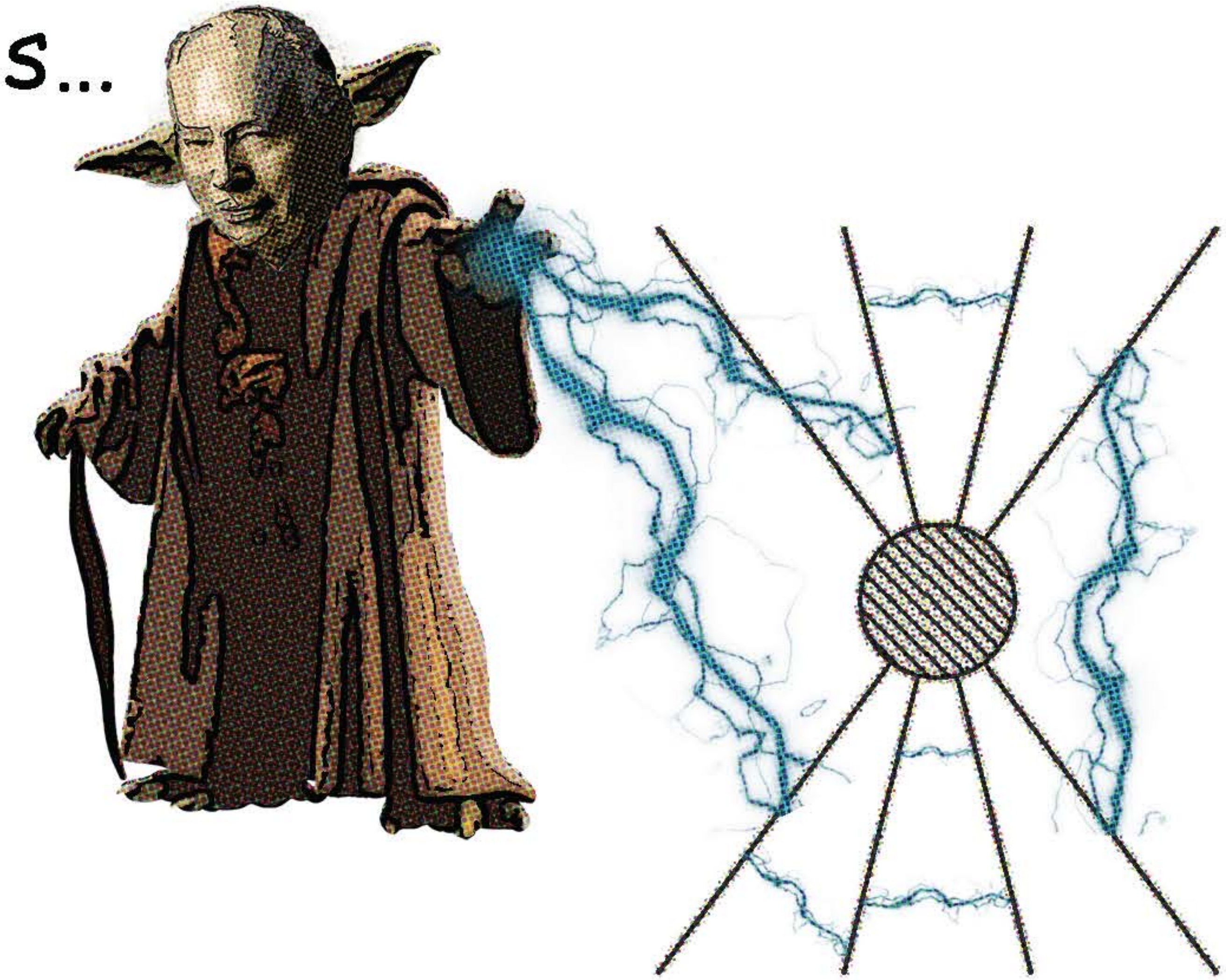
Our story starts with Strominger's suggestion that...


...a series of separate studies from the sixties are secretly the same.

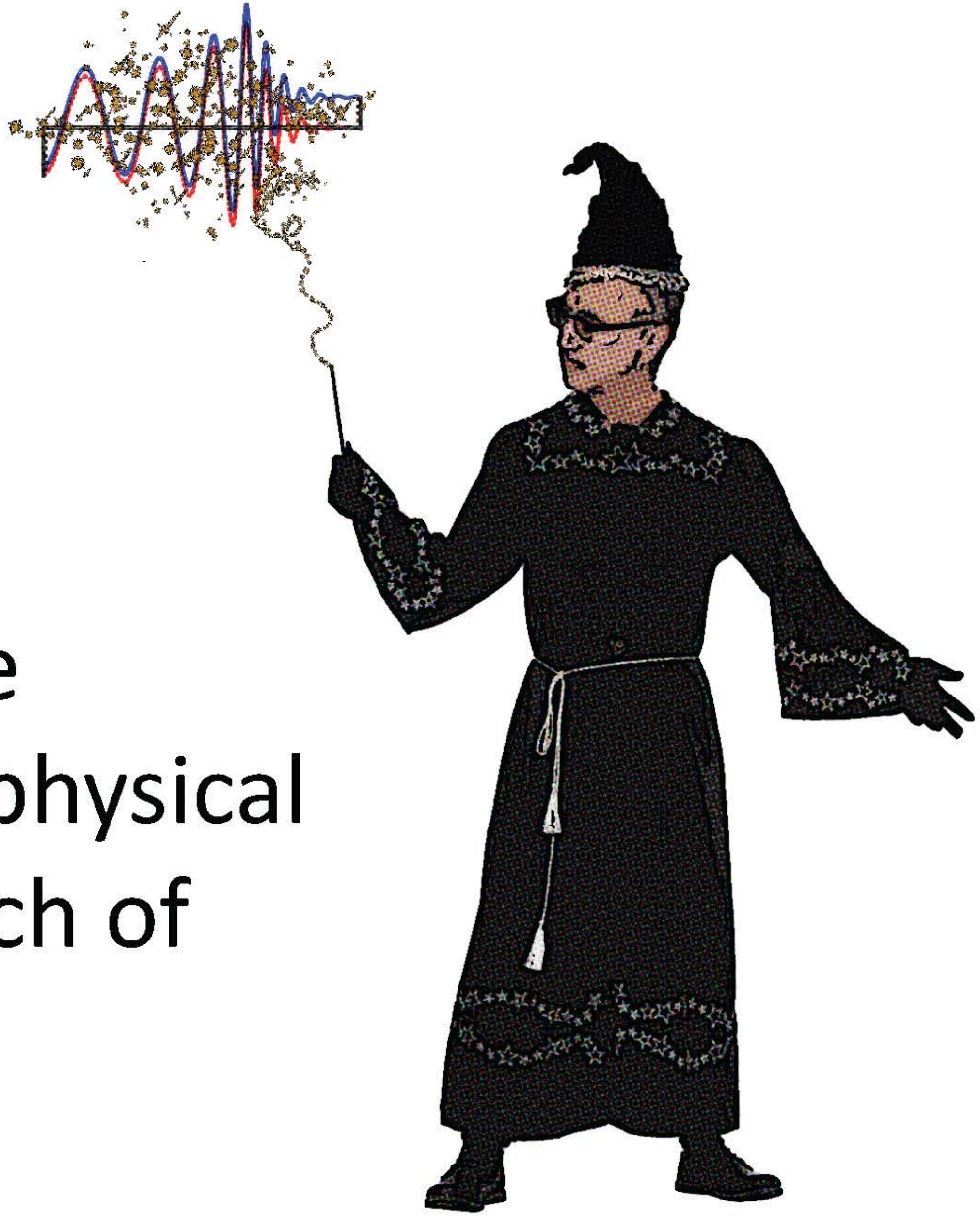


The relativists were systematizing what happens at long distances…

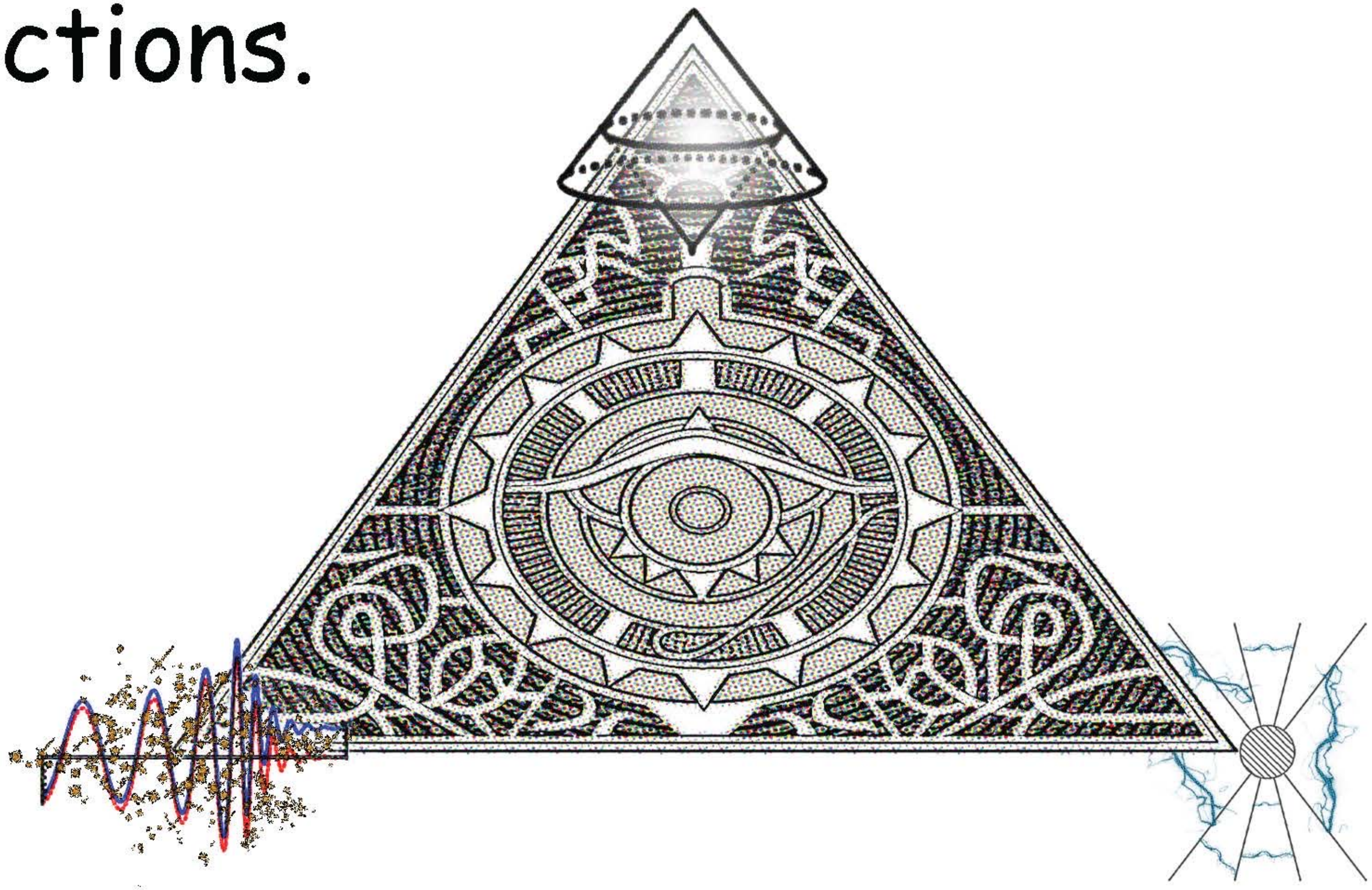
The quantum field theorists were worried about what was going on at low energies...

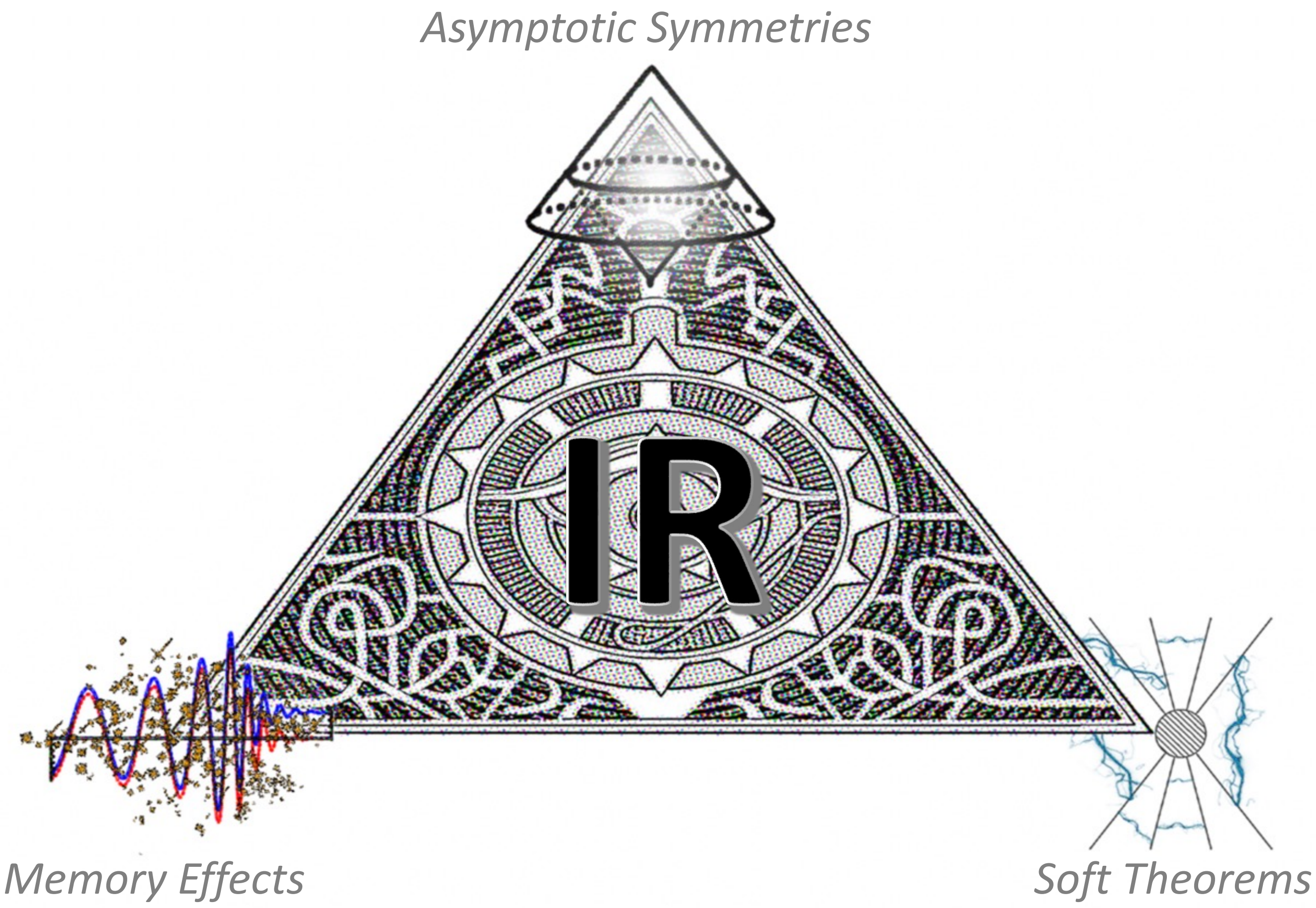


And, a little later, someone remembered there was a physical observable attached to each of these things….



Together they formed a triangle of traits universal enough to make new predictions.

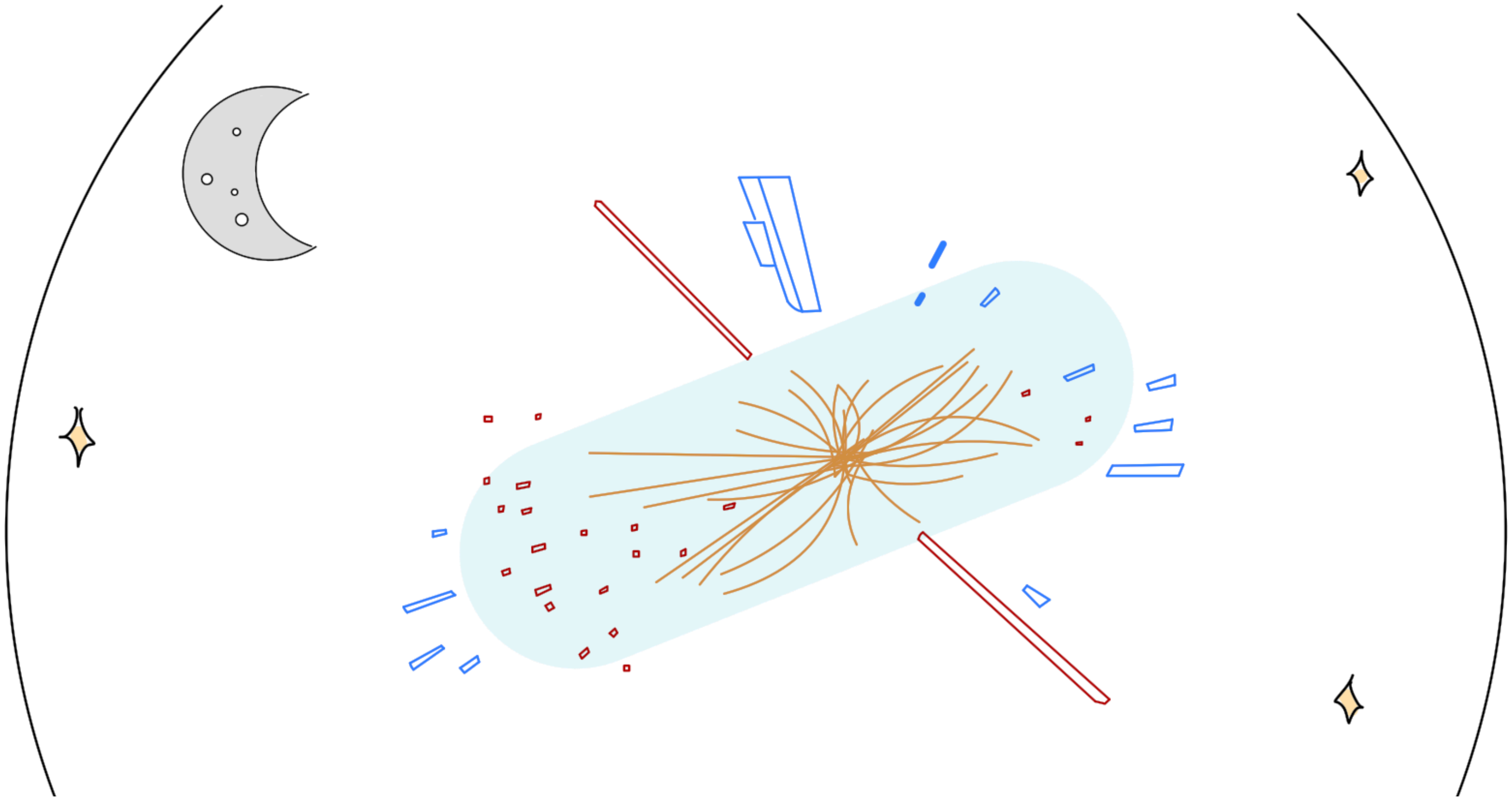




Asymptotic Symmetries
IR
Memory Effects
Soft Theorems

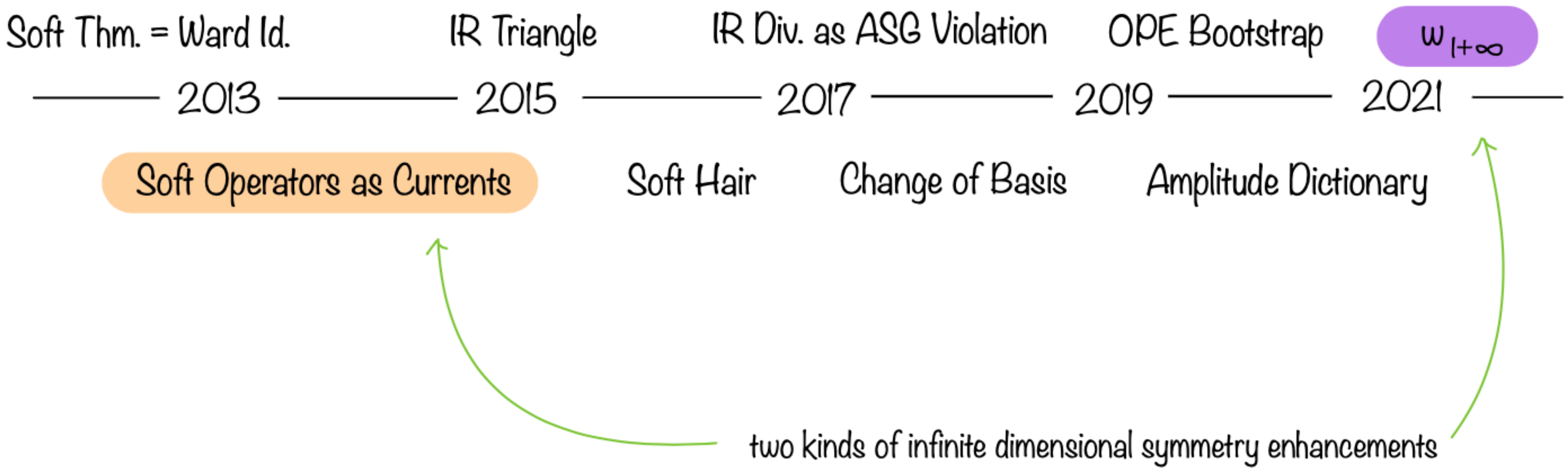
More Symmetries ⇒ More Constraints

Celestial Holography proposes a duality between scattering in asymptotically flat spacetimes…

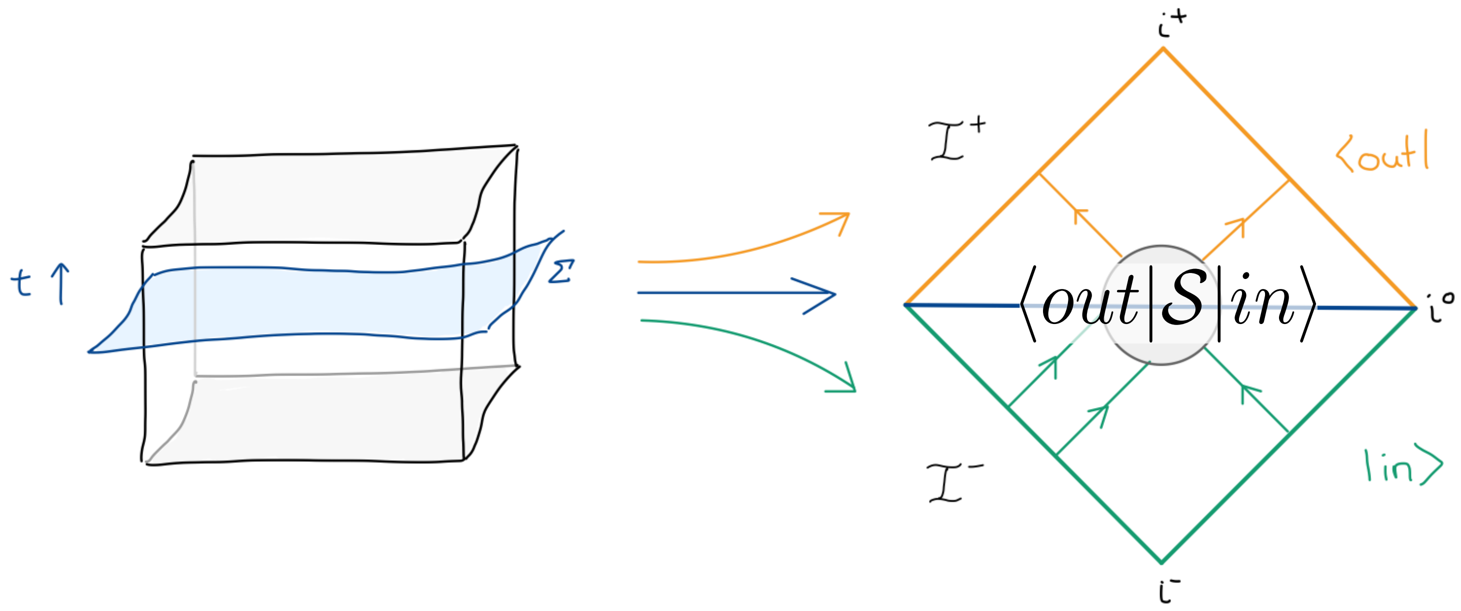


… and a CFT living on the celestial sphere.

The main motivation comes from the link between soft theorems and asymptotic symmetries and our ability to recast operators as currents in a codimension 2 CFT.

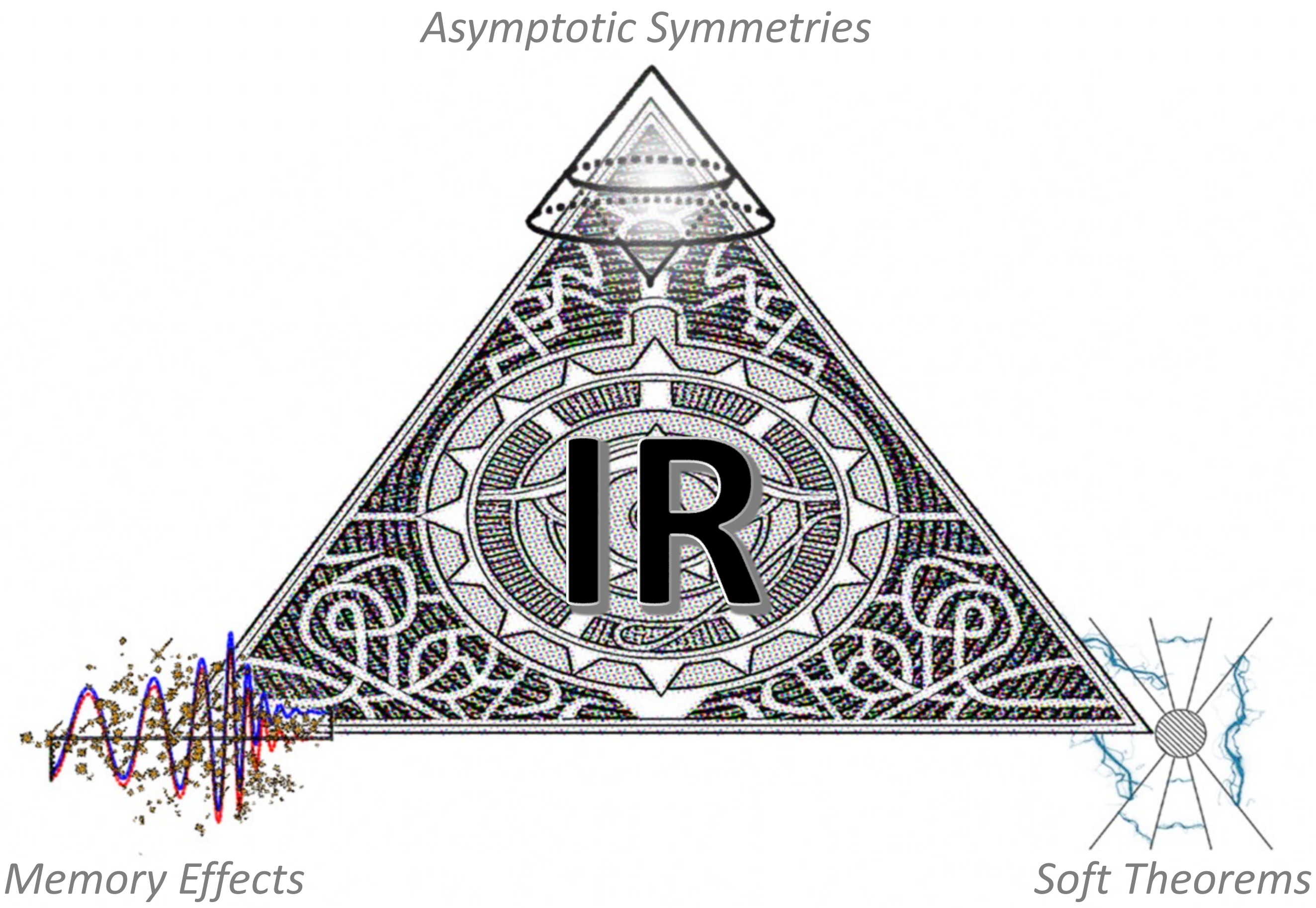


The central object of study is the scattering matrix…



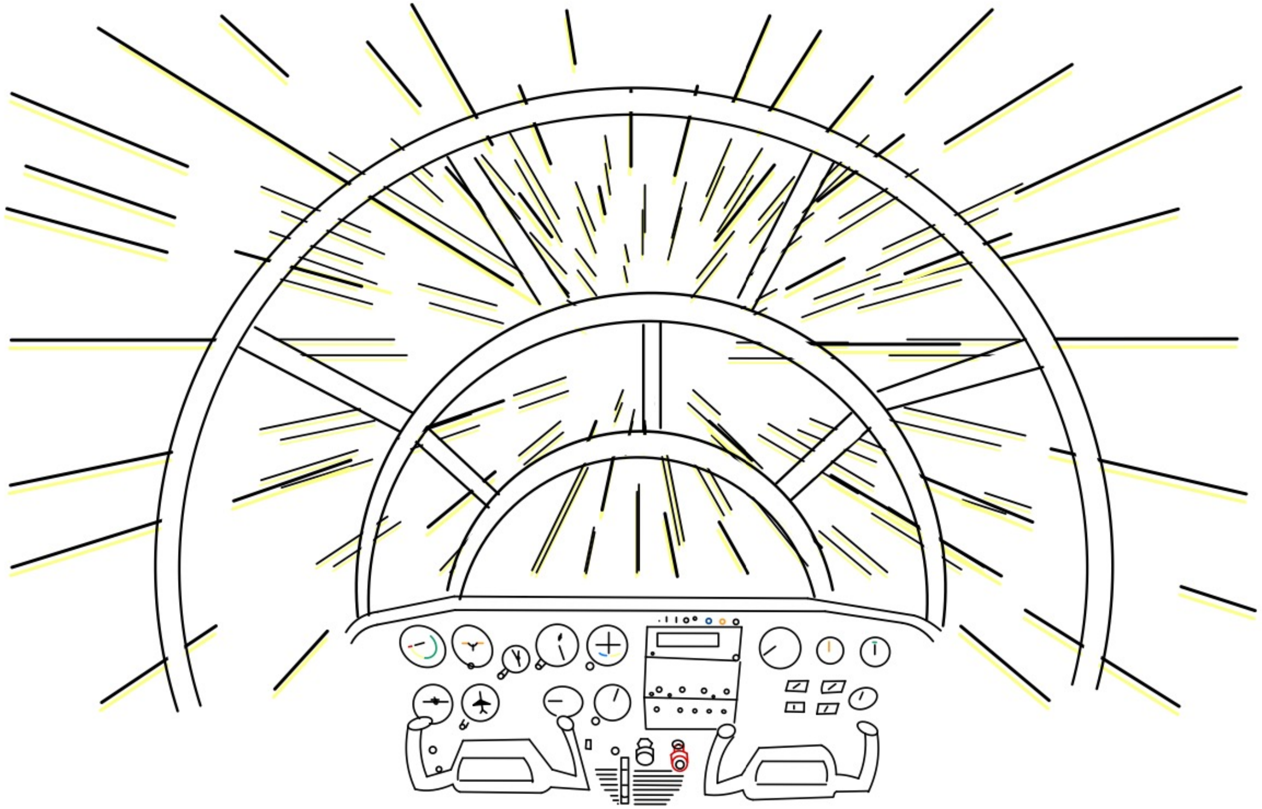
… which we can phrase the scattering problem in terms of boundary correlators.

This let’s us merge our understanding of asymptotic symmetries with IR behavior of the S-matrix.



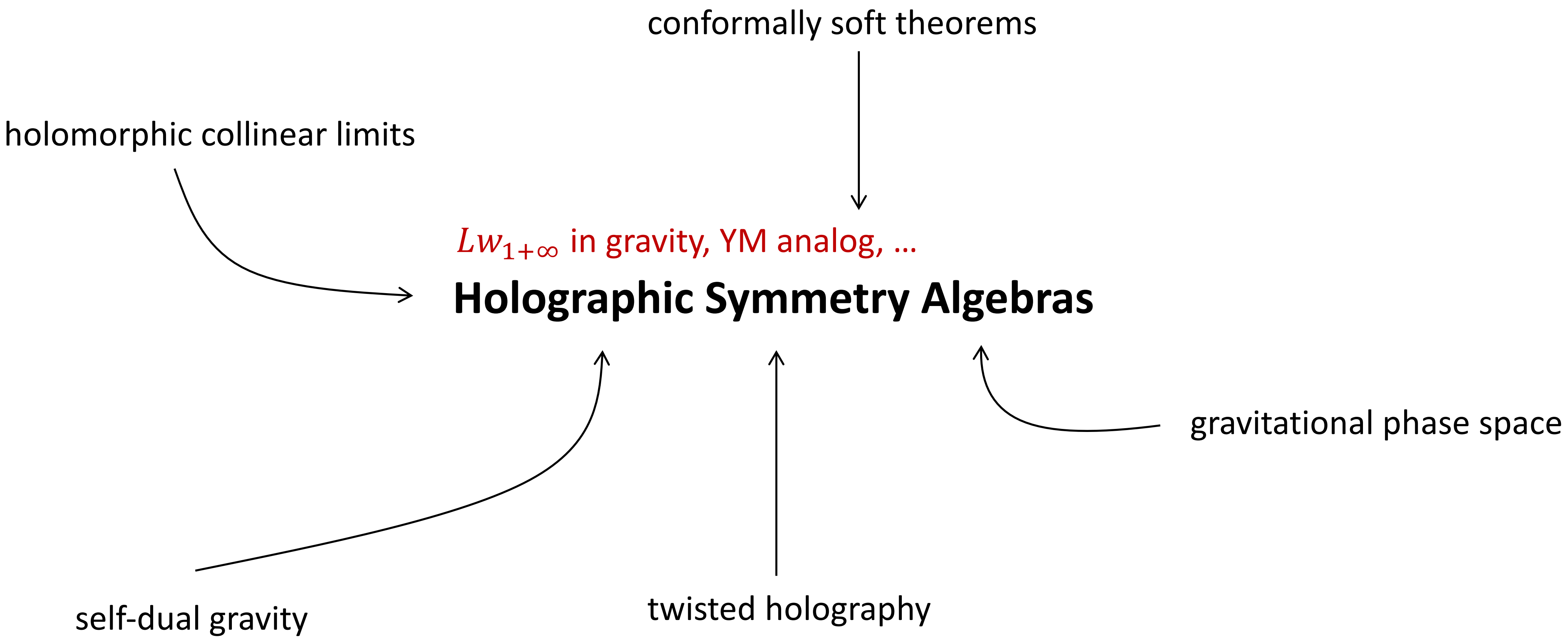
… giving a beautiful set of connections that generalize to many examples.

Now Lorentz transformations of Minkowski space…



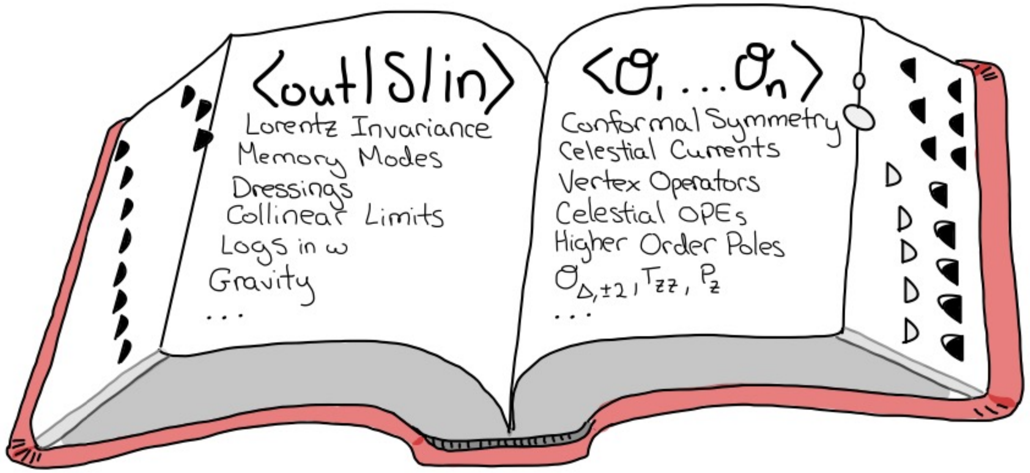
… act as global conformal transformations on the celestial sphere.

Celestographers like boost eigenstates because we get additional currents…

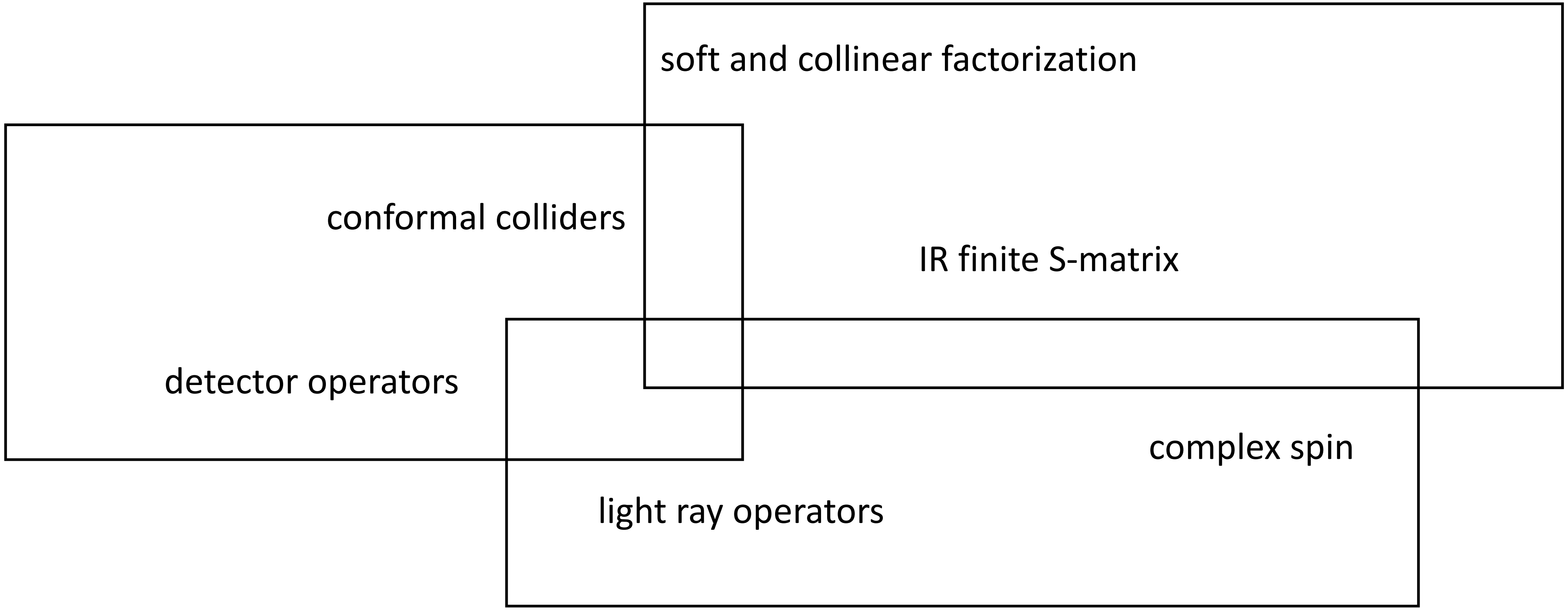


Some successes from this program include…

- *New soft theorems connected to ASGs*
- *New observable memory effects to be detected*
- *Rephrasing of soft dressings used to define an IR finite S-matrix*
- *Constraints on black hole evaporation*
- *Analytic features of quantum gravity in the boost-weight plane*
- *Collinear limits as a celestial OPE*
- *Towers of symmetries beyond the ASG analysis*
- *Connections to twistor theory*
- *Possible top down constructions from twisted holography*
- *…*



But there are many other ventures we should be able to make more concrete contact with…



… even just considering the kinematics.

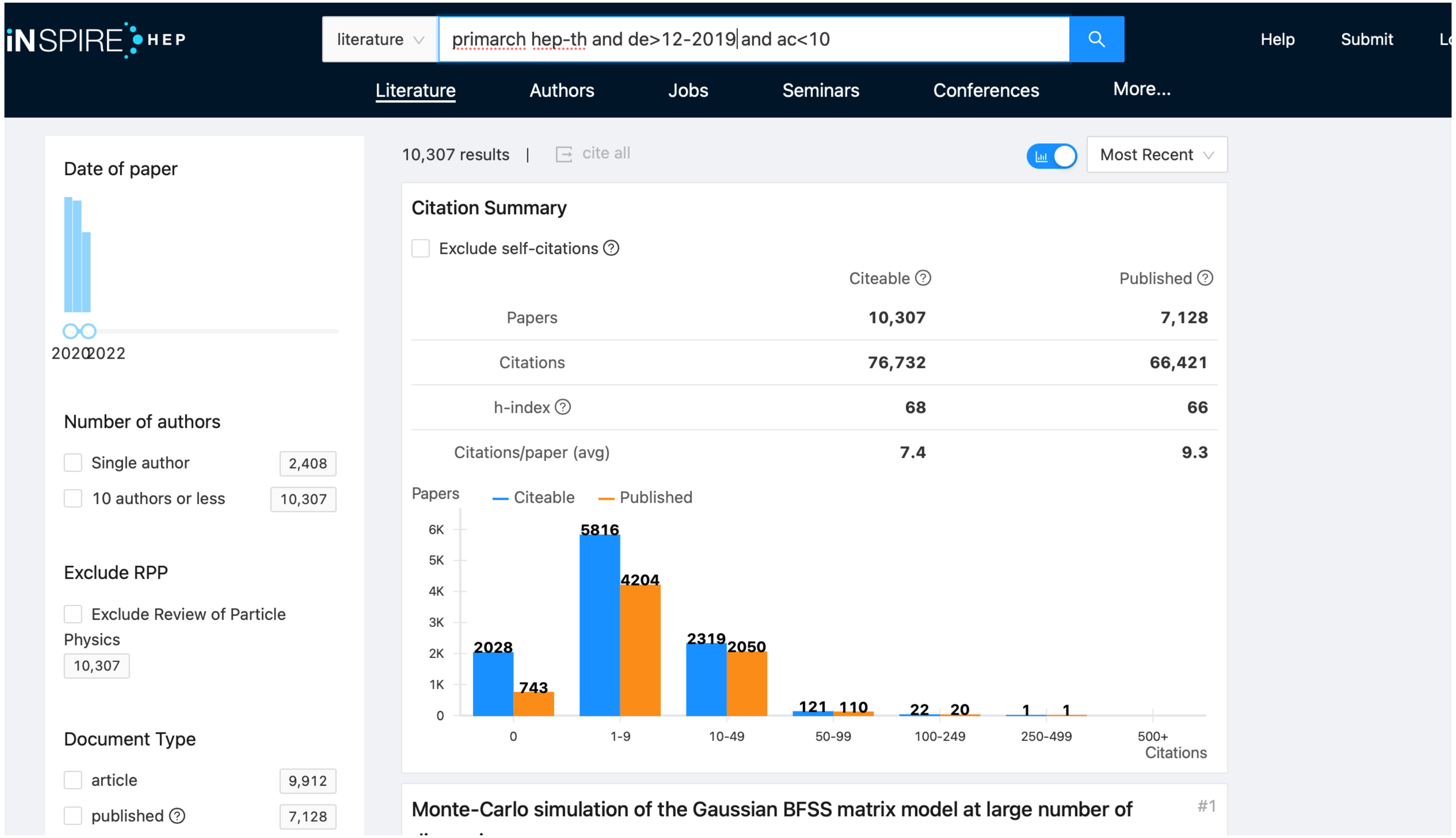
CHI Celestial Holography initiative

?

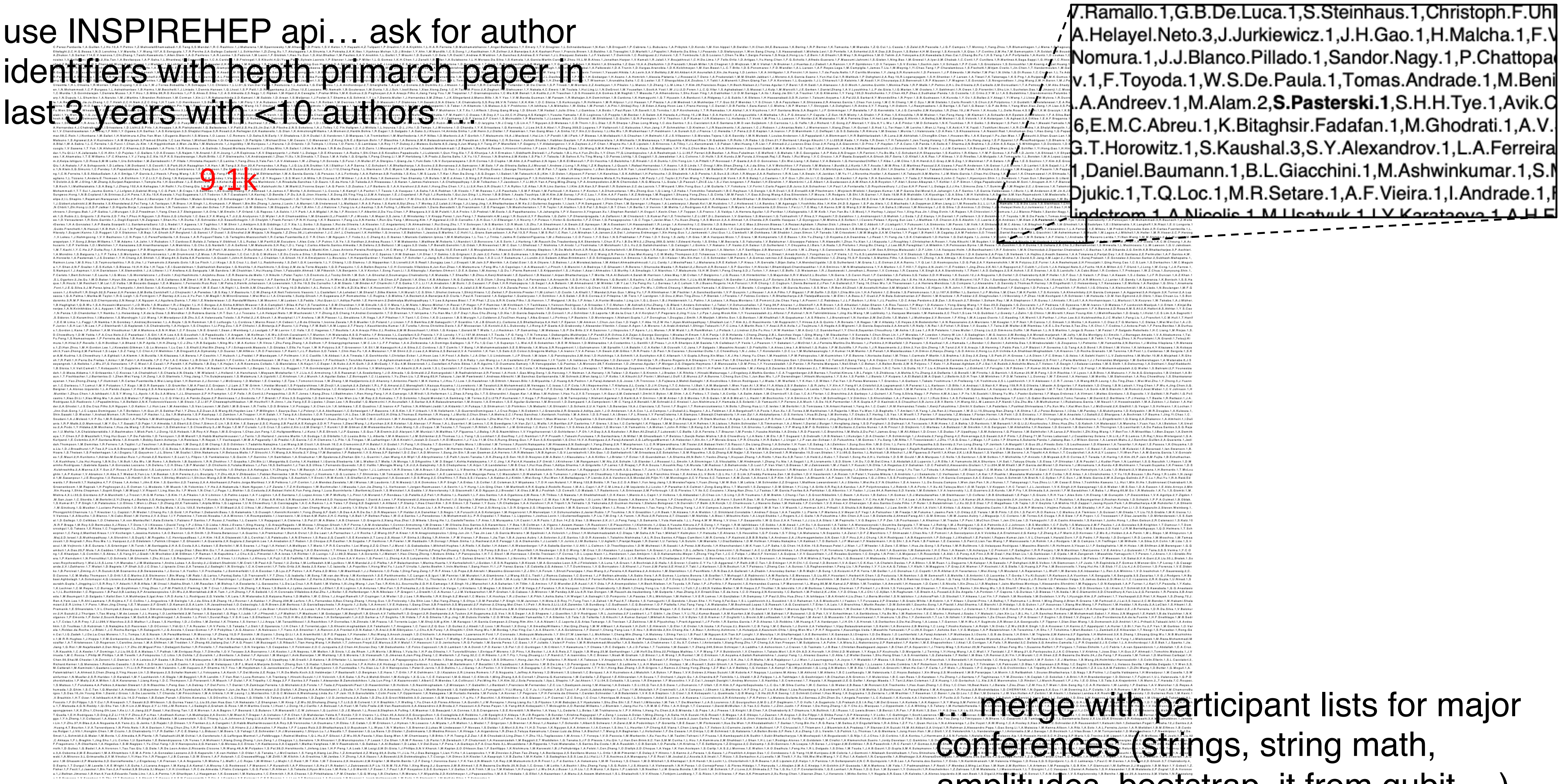
↪

What is Strings?

Who
~~What~~ is Strings?


INSPIRE HEP
literature
primarch hep-th and de>12-2019 and ac<10
Help
Submit
Literature
Authors
Jobs
Seminars
Conferences
More...
Date of paper
2020
2022
Number of authors
Single author 2,408
10 authors or less 10,307
Exclude RPP
Exclude Review of Particle Physics 10,307
Document Type
article 9,912
published 7,128
10,307 results
cite all
Most Recent
Citation Summary
Exclude self-citations
Citeable
Published
Papers 10,307 7,128
Citations 76,732 66,421
h-index 68 66
Citations/paper (avg) 7.4 9.3
Papers
Citeable
Published
6K
5K
4K
3K
2K
1K
0
2028
743
5816
4204
2319
2050
121
110
22
20
1
1
0
1-9
10-49
50-99
100-249
250-499
500+
Citations
Monte-Carlo simulation of the Gaussian BFSS matrix model at large number of
#1

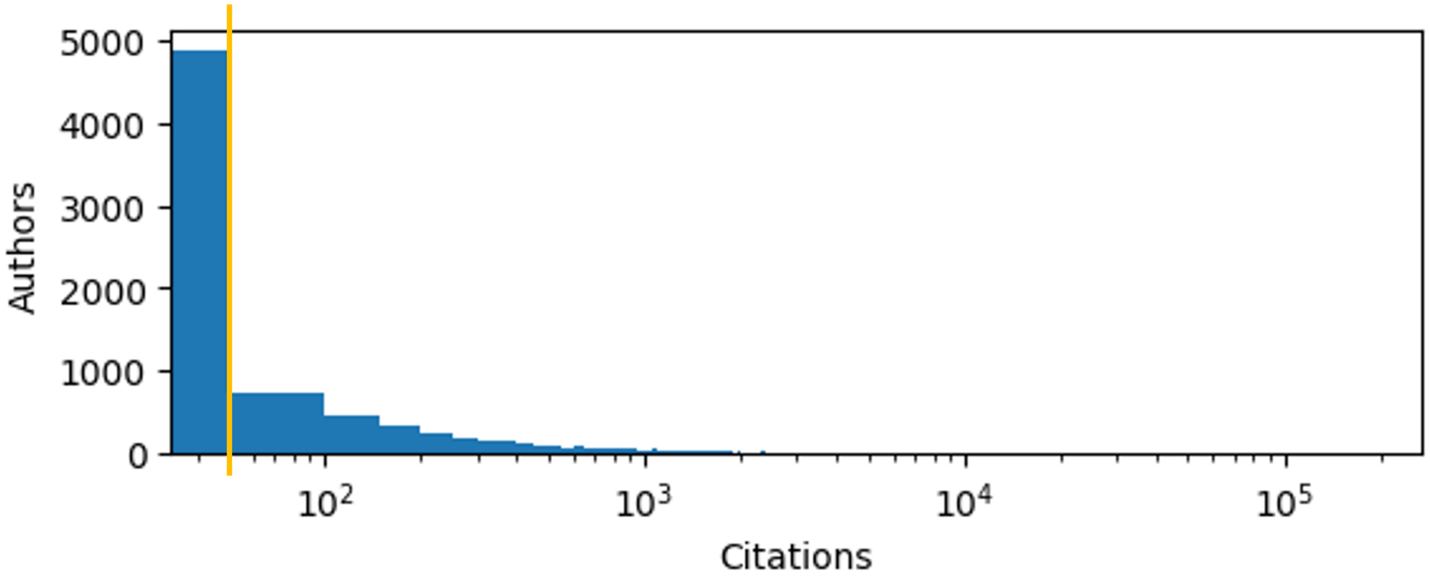
use INSPIREHEP api… ask for author identifiers with hepth primarch paper in last 3 years with <10 authors …



… merge with participant lists for major conferences (strings, string math, amplitudes, bootstrap, it from qubit …)

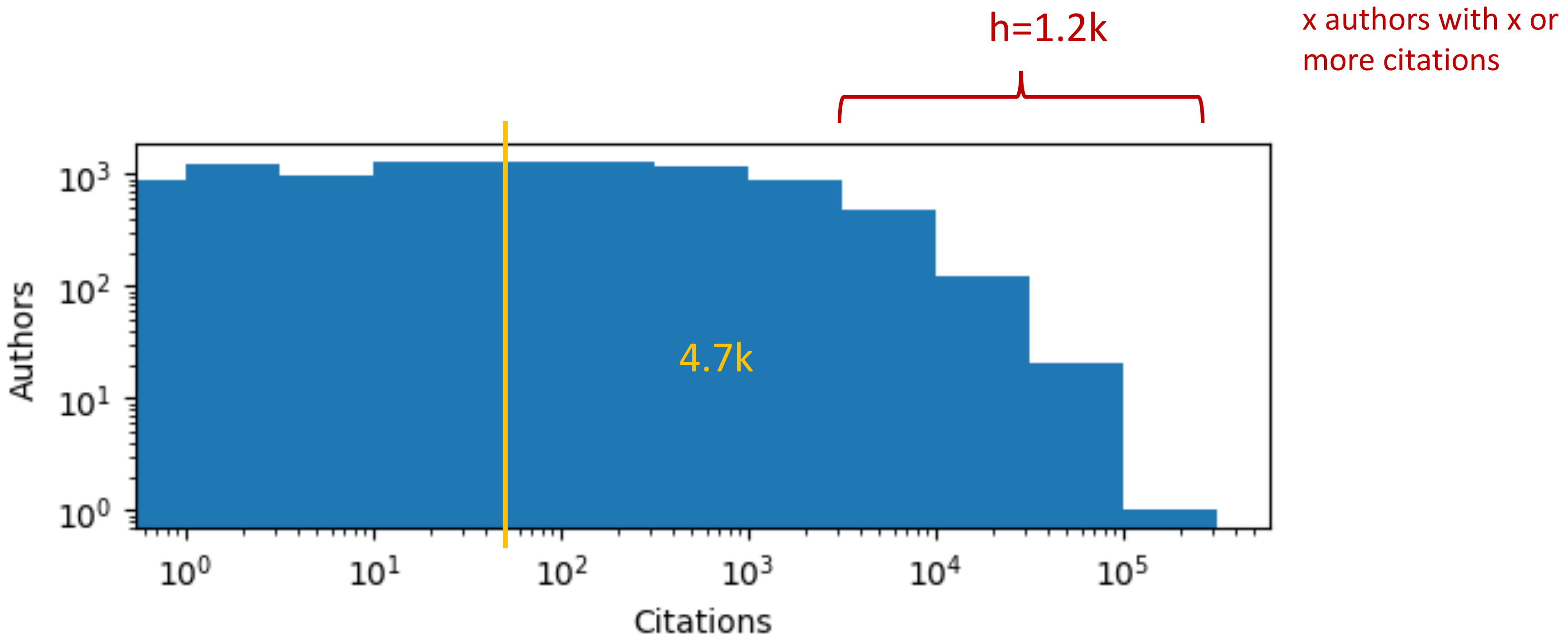
9.5k

Still an overestimate since this includes a lot of people entering the research pipeline….



…. imposing an IR cutoff > 50 hep-th citations removes half

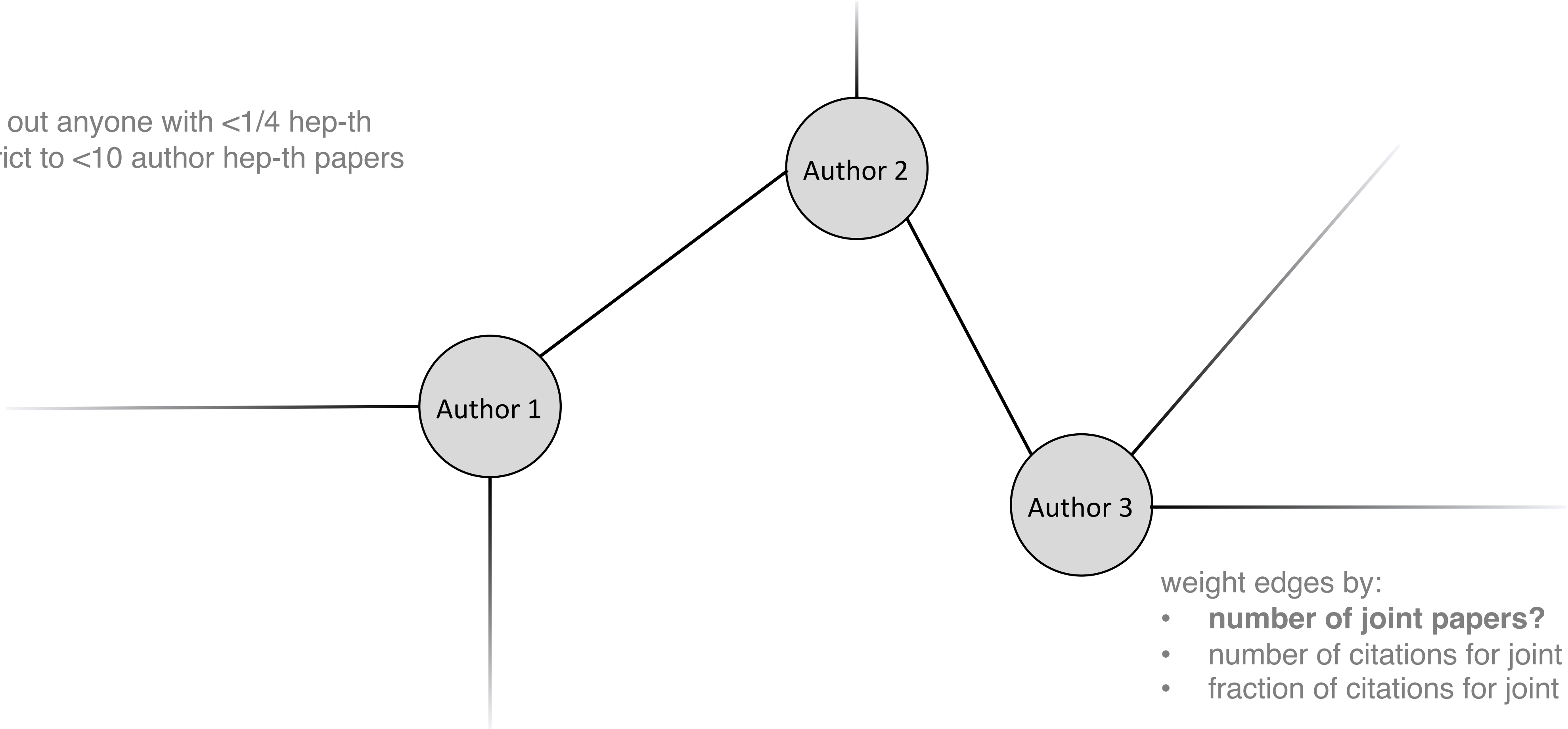
Still an overestimate since this includes a lot of people entering the research pipeline….



…. imposing an IR cutoff > 50 hep-th citations removes half

So let’s look at these top 1.2k over the last 10 years…

filter out anyone with <1/4 hep-th
restrict to <10 author hep-th papers



weight edges by:

- **number of joint papers?**
- number of citations for joint papers?
- fraction of citations for joint papers?

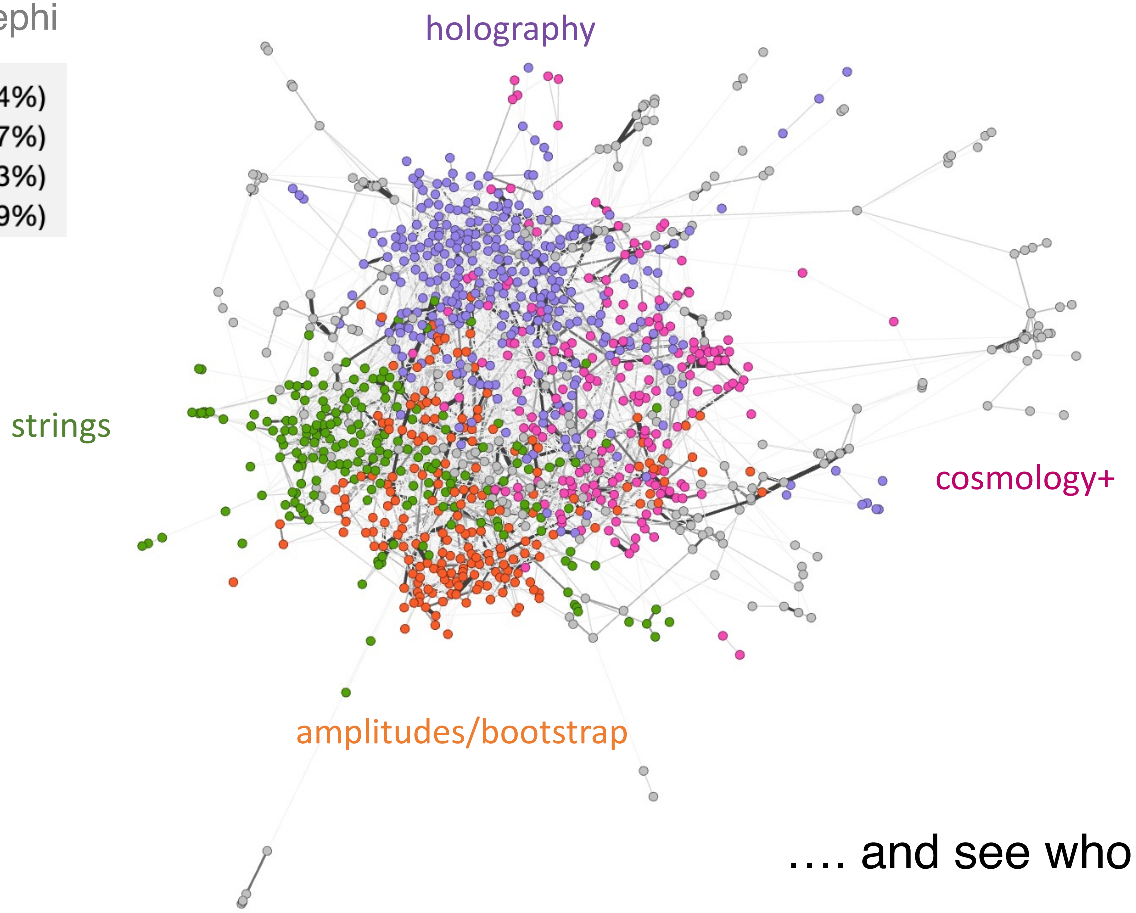
…. and see who’s worked with who

some hep-th precedents
http://www.casos.cs.cmu.edu/computational_tools/datasets/external/hep-th/index11.php (1995-1999 by M. Newman)
https://snap.stanford.edu/data/ca-HepTh.html (1993-2003 by J. Leskovec)
a recent quant-ph study
https://arxiv.org/pdf/2112.03403.pdf

So let’s look at these top 1.2k over the last 10 years…

can identify communities using Gephi

■	6	(25.84%)
■	1	(16.47%)
■	0	(16.13%)
■	2	(15.79%)



…. and see who’s worked with who

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can identify communities using Gephi

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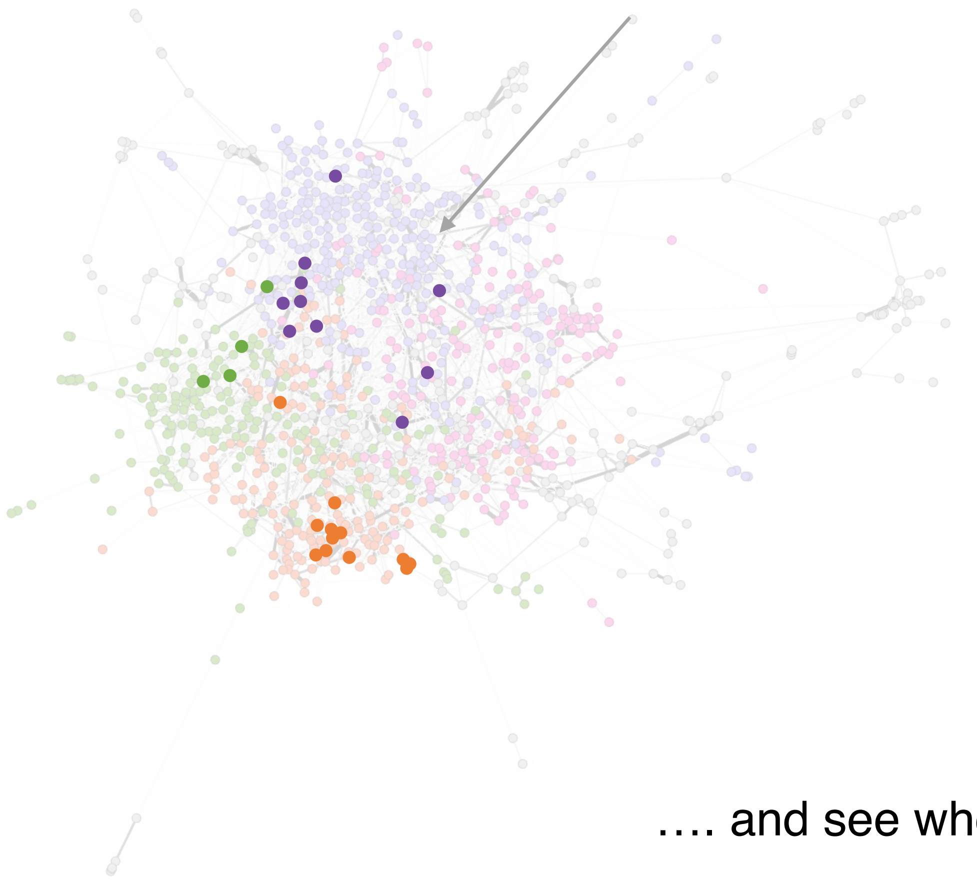

…. and see who’s worked with who

Celestial Holography initiative


EFFECTIVE FIELD THEORY
CHERN-SIMONS THEORY
ADS/CFT CORRESPONDENCE
COSMOLOGY
QED
BLACK HOLES
AMPLITUDES
RELATIVITY
SOFT THEOREMS
MEMORY
STRING THEORY
CONFORMAL FIELD THEORY
TWISTOR THEORY
QED
QUANTUM FIELDS
GENERAL RELATIVITY
GRAVITATION