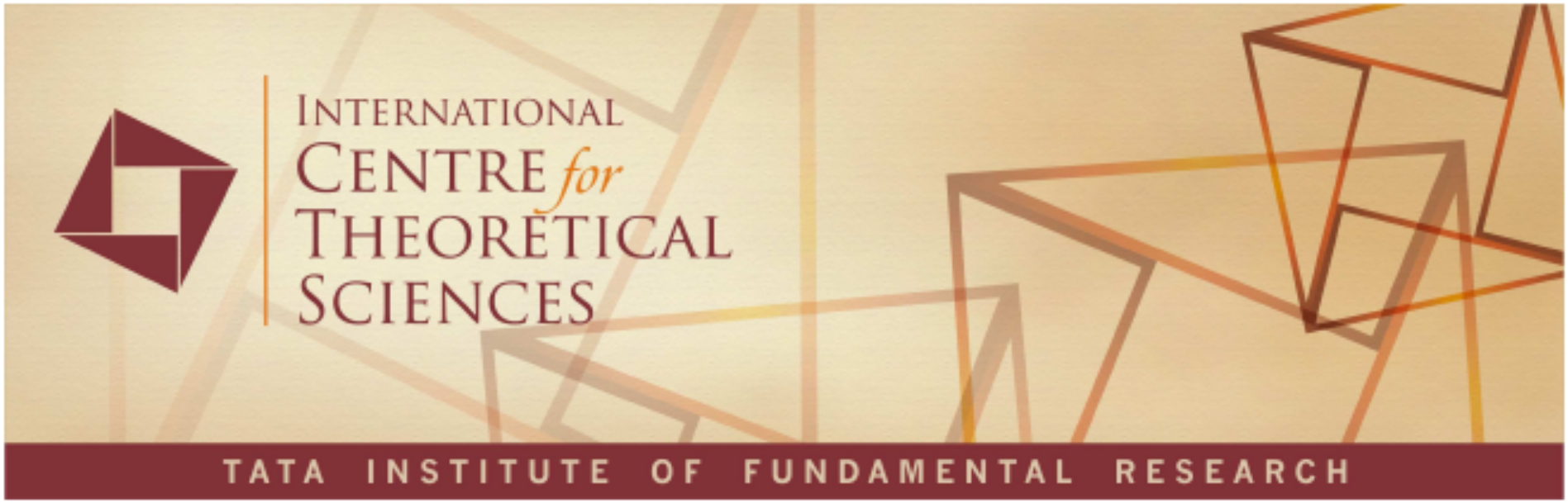

String Theory and the Hidden Structure of Space-time

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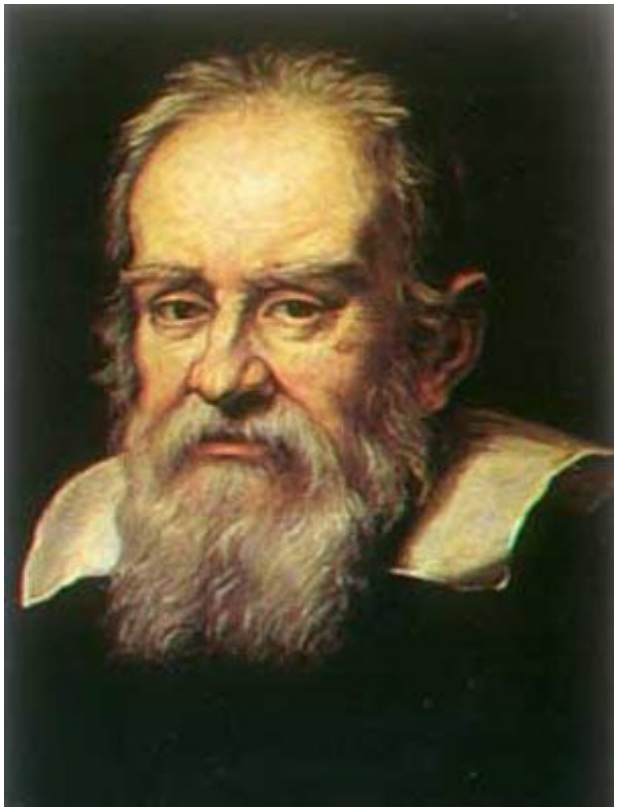
Our story…

- The force of gravity shapes our universe more than any other force that we know, yet it is the least understood and presents the greatest challenge for those who are in search of the fundamental laws of nature.
- I will take you through this story from the time of Galileo to Einstein to present day String Theory…
- 2015 celebrates 100 years of Einstein's theory

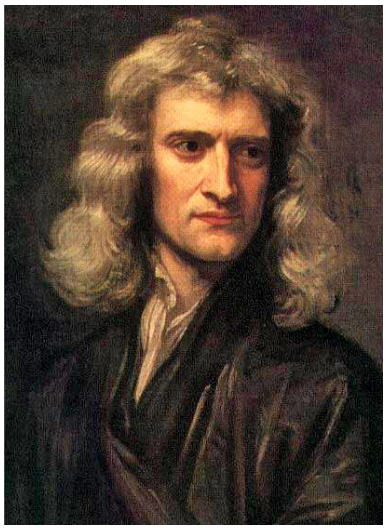
Galileo

Discovered a new law of Gravity experimentally



Gravity acts in the same way on all bodies: they fall in the same way independent of their mass…

Newton's Law of Gravitation



$$F_{grav} = G_N \frac{M_1 M_2}{r^2}$$

- Universal law of gravitation acts in `static' space and time (Principia 1687)
- Applies to `apples' and the `moon'
- **The force between objects acts instantaneously between objects separated by a distance `r'.**

Electrodynamics and Relativity

Electrodynamics (1861)

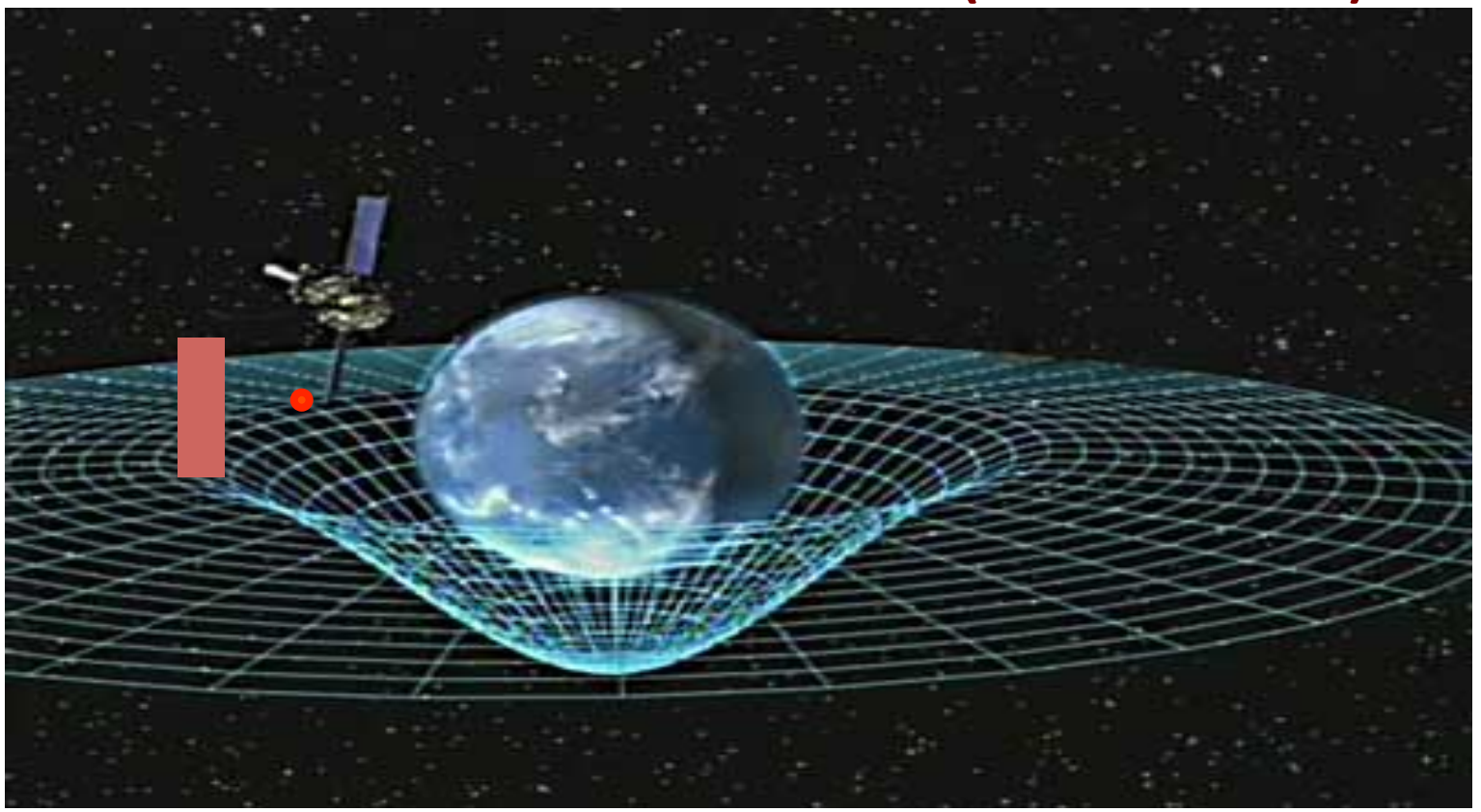
- Maxwell (1861) completes the laws of electrodynamics and demonstrates that light is an electromagnetic wave moving with a speed $c=3.1 \times 10^5$ km/sec
- Profound revision of the view of space and time

Special & General Relativity 1905 & 1915

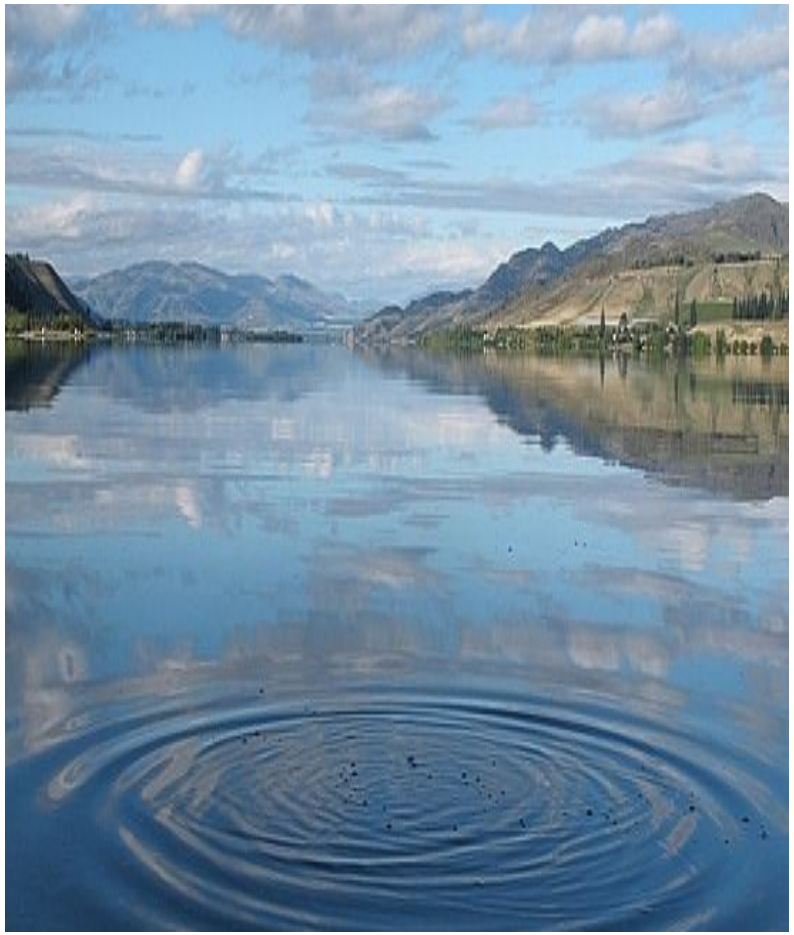
- Einstein: Simultaneity of events is observer dependent
- Newton's law of gravity with instantaneous interaction needs revision
- **General Relativity: Gravity is manifested by the curvature of space-time**

Gravity is inherent in space-time. Gravitational effects are described by the warping of the fabric of space-time

"matter tells space-time how to curve, and curved space tells matter how to move"(John Wheeler)



An Analogy: Water Waves



Drop a big pebble in a calm lake

It will cause a wave (distortion) to travel outwards from where it was dropped.

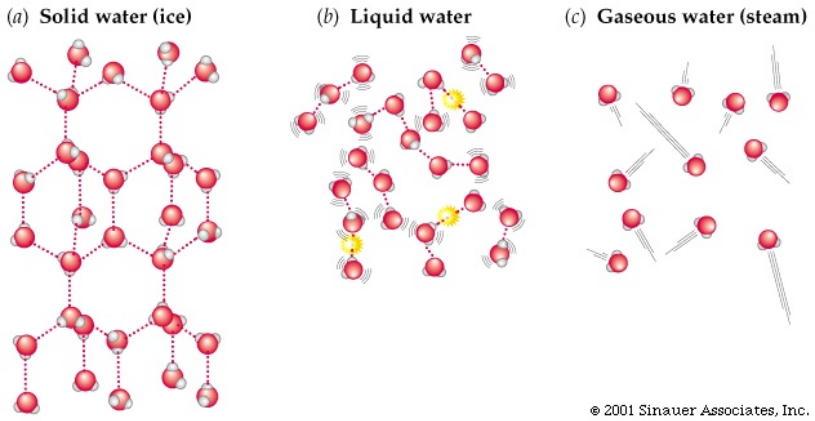
The wave will travel at the speed of sound in water and its effect will be felt a distance away.

The passing wave will wiggle a small sized object floating in the water!

There is a cause and an effect communicated by a wave traveling at a definitive speed.

The hidden structure of water/space-time?

- Water has a molecular structure underlying its smoothness

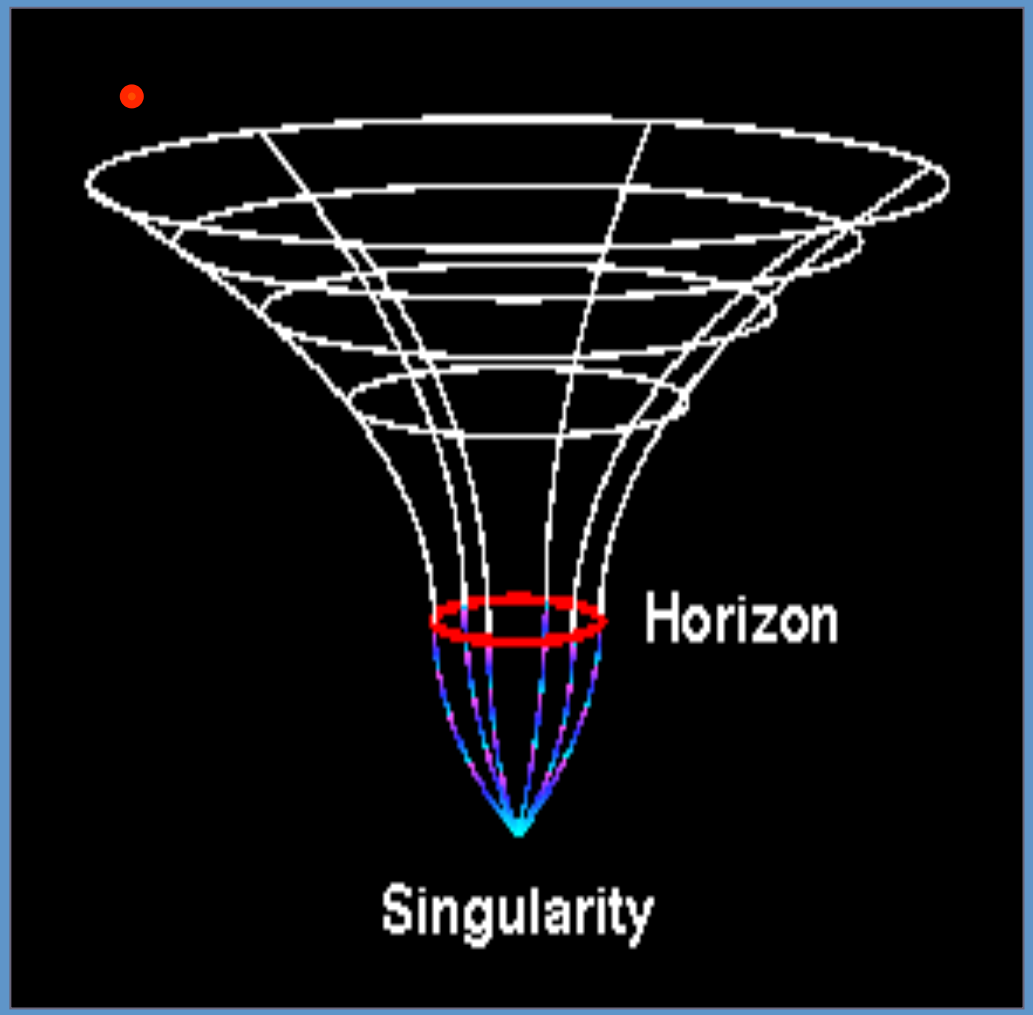


What is the hidden structure underlying the geometry of space-time?

- What are the analogues of the molecules of water in the geometrical gravity theory of Einstein?

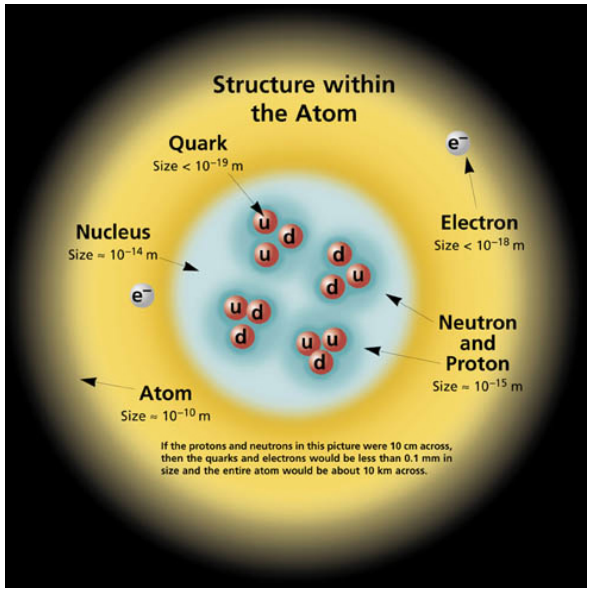
- Clue in the study of **black holes** **(which are predicted by Einstein's theory and exist in nature)**… **in String Theory**

Black Holes: Light cannot escape from within the Horizon



Quantum Mechanics

- A 20th century scientific revolution. Governs all microscopic phenomena…

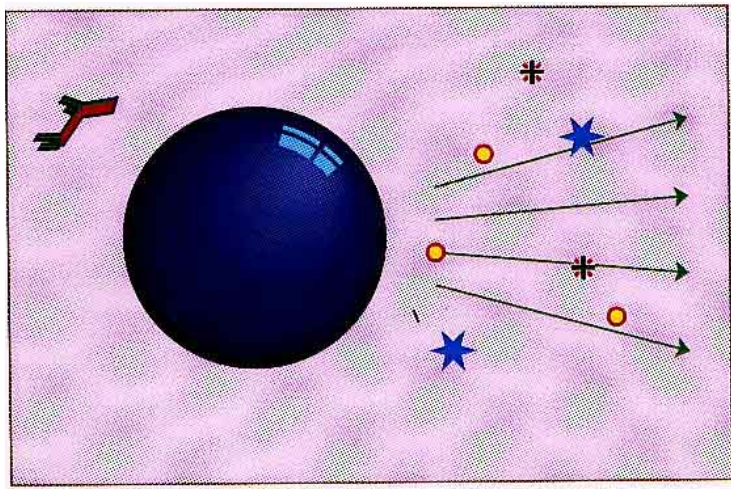


- Electronic devices, lasers, colliding elementary particles in the LHC in Geneva all follow the laws of quantum mechanics

Quantum Mechanics and Black Holes-1

- Black holes are hot (Hawking): $T = \frac{\hbar c^3}{G_N M}$
- $T_{sun} = 3.6\ 10^{-7}$ K
- $T_{earth} = 0.1$ K
- $T_{M=10^{18}\,kg} = 7000$ K (white light)
- Hot bodies have energy in the form of heat which is measured by a quantity `S' called `Entropy'.
- Bekenstein-Hawking: $S = \frac{Area}{(10^{-33}\ cm)^2}$
- *Area* is of the horizon of the black hole

Black holes and Quantum Mechanics-II



Black holes are not black due to quantum effects

They evaporate by radiating (Hawking radiation)

A black hole forms in various ways, but it always evaporates in the same way leading to **information loss**

Information loss

Boltzmann

Information loss is not consistent with quantum mechanics. It is due to the averaging process when there are a large number of internal states N.

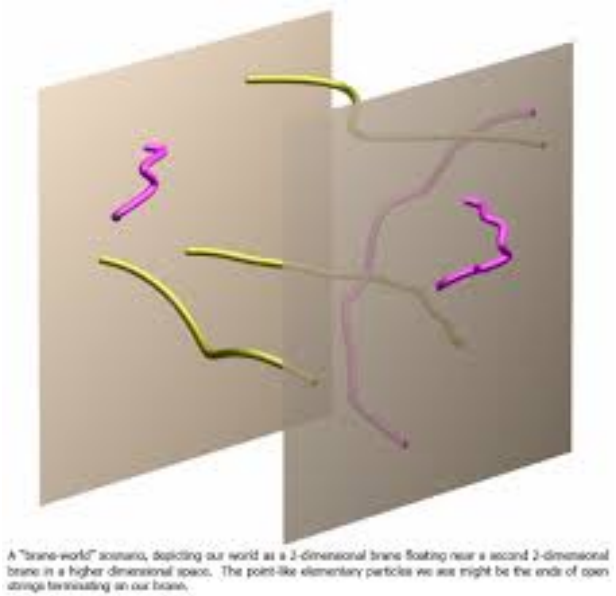
The entropy is a measure of the number of internal states that make up the black hole $\mathbf{S_{boltzmann} = klogN}$

Is it true that $S_{blackhole} = S = \frac{Area}{(10^{-33}\,cm)^2}$ = klogN ? **YES**

"Atoms" of Space-time

- String theory has the degrees of freedom that underlie the smooth geometric description called `branes' (Joe Polchinski)

e.g. 2-branes



A "brane-world" scenario, depicting our world as a 3-dimensional brane floating near a second 3-dimensional brane in a higher dimensional space. The point-like elementary particles we see might be the ends of open strings terminating on our brane.

- They are `analogous' to the molecules of water which are the underlying reality of the smooth fluid.

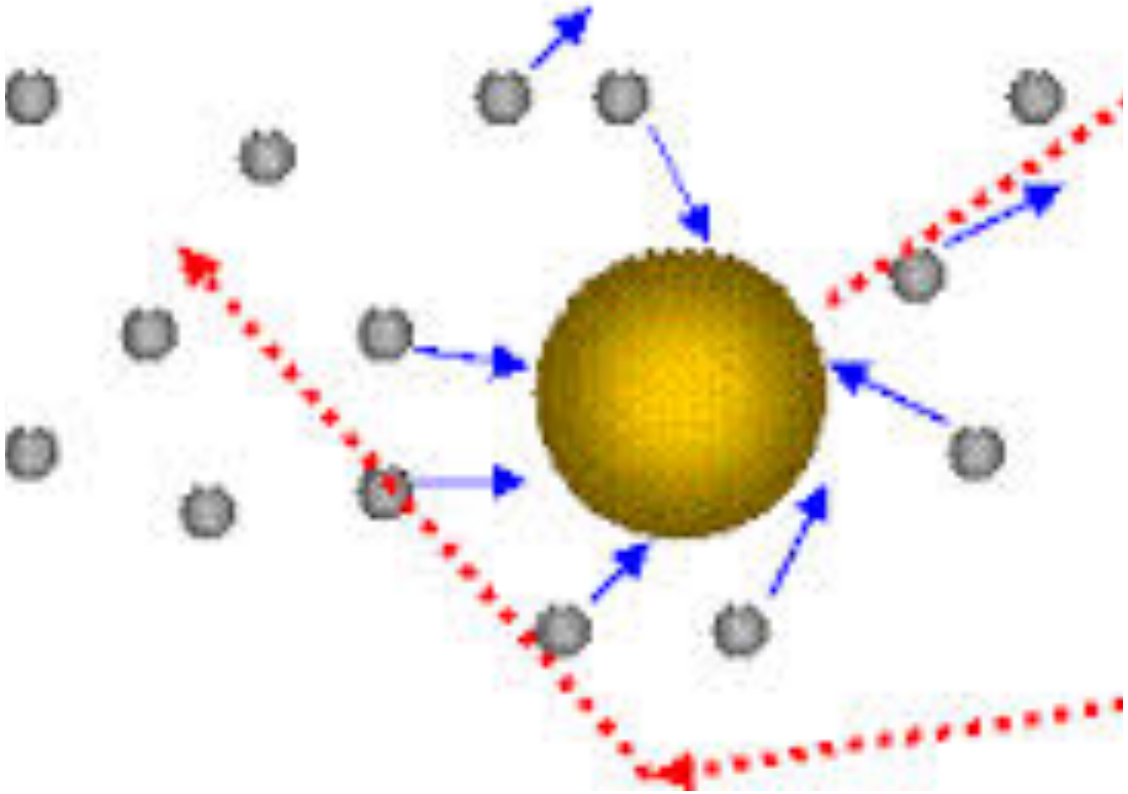
Modeling Black Holes in String Theory

- **Temperature and entropy** of a class of black holes using the microscopic underlying structures agrees with the same formulas derived from Einstein's theory (A. Strominger and C. Vafa)

- **Hawking radiation** calculated using the underlying structure also agrees with Hawking's formula (A. Dhar, G. Mandal, S. R. Wadia; S. Das, S. Mathur)

- The analogy with fluid dynamics can be made more precise using the fact that **gravity is `holographic'** (J. Maldacena; E. Witten; D. Son, S. Minwalla and others)

- One can compute **finite and systematic answers to all quantum processes of gravity** in the framework of string theory (A. Dabholkar, A. Sen and others)



Indirect tests of Atomic Structure

Random motion of `Brownian particles' reflects the presence of underlying atomic/molecular matter (Einstein 1905, Perrin 1909).

What lessons can be learnt for GR from this?

Epilogue

- The smooth space-time of our experience is an approximate description of an underlying structure that is needed for a complete (quantum) description of gravity.

- This is a subject of intense current research in string theory.