EvAneScent LAwS

GRAVITY EVADES ENERGY CONSERVATION AND EATS ENTROPY ON THE COSMOLOGICAL SCALE.

Charles W Misner
University of Maryland

Outline

- Context: Structure of Scientific Knowledge
- Relations between theories
  - Correspondence principles
  - Emergent properties and laws
  - Evanescent properties and laws
- Examples of Evanescent Laws
- Cosmological evanescence of
  - entropy and energy

Structure of Scientific Knowledge

- Problem: “It’s just a theory”
- Excuse: Popper and Kuhn --

  Current theory could be falsified;
  The better theory could bring in
  new objects and actions.
- Solution: Use only “Certified Theories”
  (which have already been shown false)
  in the domains where they are certified.

Prime Example Certified Theory

- Newtonian Mechanics has many limitations
  - Special relativity
  - Quantum mechanics
  - Einstein gravity
  - Unforseen sensitivity to initial conditions
- But many active uses
- Newtonian mechanics is not a dead theory like phlogiston.

Structure of Scientific Knowledge

- Certified Theory defined:

  A theory whose validity has been certified by better theories, and whose domain of usefulness is limited by known failures where those better theories are needed, but which continues in use as more insightful than its more complicated replacements,

Structure of Scientific Knowledge

- Relations between useful theories:
  - Correspondence Principles
    - E.g., GR gives Newtonian gravity in weak fields, special relativity in small regions.
  - Emergent laws and properties
    - E.g., Pressure and Temperature defined for large systems, but not for single molecules, (cf. Philip Anderson)
  - Evanescent laws and properties
    - The main topic for this talk

Evanescent Laws

Origin of the name:

In the ray optics limit of optical wave theory one meets total internal reflection using Snell's law.
If this is analyzed using wave optics one finds that beyond the reflection interface there is an "evanescent wave" which disappears exponentially beyond the interface.

Some physics laws also disappear beyond applicable boundaries.

Evanescent Laws

- Examples
  - Conservation of QCD color charge as one moves into atomic physics
  - Coulomb law as one calculates the motions of solar system planets
  - Schrödinger equation in molecular genetics
  - *Energy on cosmological scales*
  - *Entropy in large self-gravitating systems*

Evanescent Laws

- A law or property can be called Evanescent when in some domain either
  - It becomes irrelevant or useless
  - It is indefinable or misleading
  - Its normal consequences can be evaded
  - It (rarely) is incorrect in some domain
- We will make the evanescence case for energy and entropy on the cosmological scale.

General Relativity

GR is a “proto-certified” theory

- Expected to graduate to full certified status
- Its limits/failures not yet found in data
- Not a derivative of “better theories” except very speculative ones.

I will treat cosmological energy and entropy within the framework of GR

Energy in General Relativity

- Locally (curvature negligible) use special relativity and its energy rules
- Small self-gravitating systems (e.g., solar system) use Newtonian energy rules
- Isolated systems (asymptotically flat) use ADM or related boundary integrals
- Weak short waves, use geometrical optics approximation (Isaacson)
- Use stress-energy pseudotensors carefully

Energy in General Relativity

- Recent success “Dark Matter Telescope”

GR energy pseudotensors

- Topology problems
  - ¿ Inside black holes ?
  - ¿ Closed universes ?
- Lynden-Bell, Katz, Bičák (MNRAS v272, pp150—160, 1995):
  Background (unphysical) metric can replace preferred (asympt. flat) coordinates. Validates zero total energy for closed universes (Stokes' Theorem needs real vectors.)

Evanescent Energy Law

- With total energy zero (FRW flat and negatively curved universes can also be compact), conserving that value doesn't provide much guidance.
- If a mechanism existed to insert new matter into the Universe, its mass/energy would be balanced by its gravitational potential energy of interaction with the rest of the Universe.
- GR doesn't give clear meaning to interaction energy however.

Evanescent Energy Law

- Dark energy (false vacuum or cosmological constant) formally conserves energy locally while not limiting the introduction of more.
- With $P = -\rho$ and no heat flow between one volume V in the universe and its neighbors, the first law of thermodynamics reads

  $$dU = -P\,dV = +\rho\,dV$$

  which is satisfied by $U = \rho V$ and *constant* ρ.
- Thus this form of matter/energy can expand as much as wanted with *no* energy cost!

Evanescent Entropy Law

The entropy of the Universe appears to be undefined, and its increase is in any case regularly evaded.

Evanescent Entropy Law

- "Heat Death of the Universe", a late 19th century concern, has been cancelled.
- "Heat Birth of the Universe" is now the Standard Model in Cosmology
- The mid Big Bang (Mev temperatures) is the very model of a high entropy state: hot, homogeneous, uniform temperatures, no route for heat flow to allow work to be done.
- Gravity works "out of the box"!

Evanescent Entropy Law

- Fang Li Zhi and Li Shu Xian
  Creation of the Universe (especially Chapter 6) World Scientific, 1989, ISBN 9971-50-601-7 translated by T. Kiang from the 1987 Beijing edition

- D. Lynden-Bell, “Negative Specific Heat in Astronomy, Physics and Chemistry”, arXiv:cond-mat/9812172, 10 Dec 1998

- Freeman J. Dyson: A Many-Colored Glass (U VA Press, 2007) ISBN 978-0-8139-2663-6, Chapter 4 "A Friendly Universe" (pp.61--82)

Evanescent Entropy Law

- Thermodynamic principal functions (energy, entropy, enthalpy, etc.) are extensive quantities. Two moles of a substance have twice the quantity of one under the same conditions.
- Unless widely separated, two similar galaxies don't have twice the energy of one; their gravitational interaction energy must be recognized.

Evanescent Entropy Law

A crucial factor for thermodynamics in the presence of large self-gravitating systems is that these objects (stars, star clusters, planetary system, galaxies, …) have a ***negative specific heat***.

This follows from the virial theorem which, for (Newtonian) gravity says

$$E \equiv K.E. + P.E = - K.E.$$

Thus, when energy is added (E increases), kinetic energy (temperature) decreases.

Evanescent Entropy Law

The same is true for black holes. If mass/energy is added to a black hole, its Bekenstein-Hawking temperature decreases.

Fang argues that "as long as self-gravitating systems are present [in a larger system], a stable thermal equilibrium does not exist."

From the Chandrasekhar (white dwarf) limit, through neutron stars limits, and the Oppenheimer-Snyder "continuing collapse" we know that **large systems reach no equilibrium.**

Evanescent Entropy Law

Thermodynamics treats the properties of systems in equilibrium. Non-equilibrium processes can be of interest, but their equilibrium end states can be compared by imagining a reversible sequence of equilibrium states that allow an evaluation of the state functions like energy and entropy.

Without equilibrium end states, we may consider entropy of gravitating systems to be ill-defined.

Evanescent Entropy Law

- Classical Thermodynamics claims to be agnostic as to any microscopic structure underlying the systems it treats, but if we take from statistical mechanics the idea that entropy is a measure of our ignorance of the underlying microstates, then perhaps cosmological entropy can be defined?
- Unmeasured reductionist understanding of dark matter and dark energy urges caution.
- But Bekenstein-Hawking BH entropy is defined!

Evanescent Entropy Law

If entropy is accepted, go to “Plan B”:

- Use the tax evasion--Cayman Islands’ model
- Send all the entropy you don’t like to a Black Hole Island, or buried beyond the deSitter cosmological horizon.

This works for the Earth. Hot sunlight delivers energy with low entropy content; infrared reradiation carries that energy away in a high entropy package. The net entropy export is send out into the wider universe.

Evanescent Entropy Law

Look at the results. Galaxies with black holes at their centers. Star formation and lots of activity. Even in isolated corners like the Solar System on finds gems such as Earth with biology, intelligent(?) life, and exotically organized civilizations. Each of which had to export loads of entropy to be constructed.

Entropy on the cosmological scale can be ignored. The entropy tax on progress cosmologically is evaded.