Title: Shape Dynamics: Perspectives and Problems

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Abstract: Shape Dynamics(SD) can be derived from principles that differ in significant respects from Einstein's derivation of GR. It requires a spatially closed universe and allows a smaller set of solutions than GR does for this case. There are indications that its solution space can be fully characterized and endowed with a measure. These architectonic features suggest that SD can explain the arrows of time as direct consequences of the law of the universe. They do not require special initial conditions. I will discuss these and other major issues on which SD may cast light. I will also discuss the problems that face SD.

Shape Dynamics: Prospects and Problems

Julian Barbour

Shape Dynamics Workshop, Perimeter Institute, May 15-17 2017

JB, Tim Koslowski, and Flavio Mercati,"Identification of a gravitational arrow of time", Phys. Rev. Lett. **113**, 181101 (2014)

"Entropy and the typicality of universes", arXiv: 1507.06498v2.

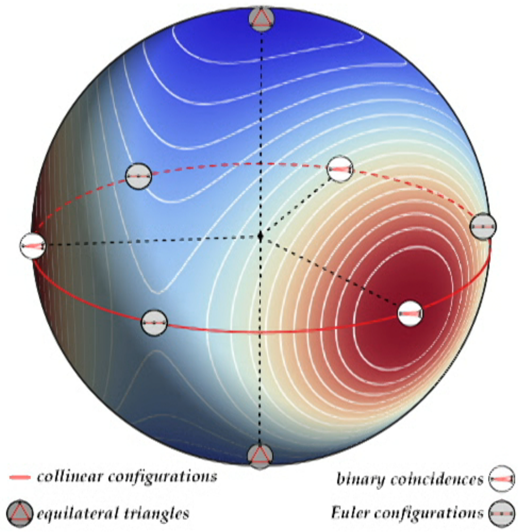
Outline

Introduction: Caloric, distance and relational N-body problem.

Some prospects and problems for discussion.

1. Origin of chronology, rods, clocks, inertial frames.
2. Attractors on Shape Space and origin of the Second Law.
3. Passage through Newtonian and Einsteinian singularities.
4. Janus-Point data and typicality of universes.
5. Quantum Gravity and representation of shapes.

0.1 The N-Body Shape Space



Shape Space S: island universe of all possible N-body mass-weighted shapes shown here with distinguished metric for the equal-mass 3-body case. Colour coding shows shape complexity C_{Shape}: $C_{\text{Shape}} = \ell_{\text{rms}}/\ell_{\text{mhl}}$, where

$$\ell_{\text{rms}} := \sqrt{\sum_{a<b} \frac{m_a m_b r_{ab}^2}{m_{\text{tot}}^2}} = \sqrt{I_{\text{cm}}/m_{\text{tot}}},$$

$$\ell_{\text{mhl}}^{-1} = \frac{1}{m_{\text{tot}}^2} \sum_{a<b} \frac{m_a m_b}{r_{ab}} = -\frac{1}{m_{\text{tot}}^2} V_{\text{New}},$$

$$C_{\text{Shape}} = -\frac{1}{m_{\text{tot}}^{5/2}} \sqrt{I_{\text{cm}}} V_{\text{New}}$$

0.2 The Aspiration of Shape Dynamics

To formulate the most parsimonious law
of a dynamically closed universe as
an undirected unparametrized curve in its shape space and
show how the local laws of physics arise from it.

In contrast, Einstein and gauge theorists,
following Faraday and Maxwell,
formulated local laws of physics and
cosmologists seek model universes compatible with them.

Shape Dynamics needs to predict the actual universe,
not all Einsteinian universes. Besides being more predictive,
it may also be more illuminating and suggest new research topics.

0.3 The Lagrange–Jacobi (Virial) Relation

If V homogeneous, $\boxed{V(\alpha\mathbf{r}_a) = \alpha^k V(\mathbf{r}_a)}$, then $\boxed{\frac{1}{2}\ddot{I}_{\text{cm}} = E_{\text{cm}} - 2(k+2)V}$

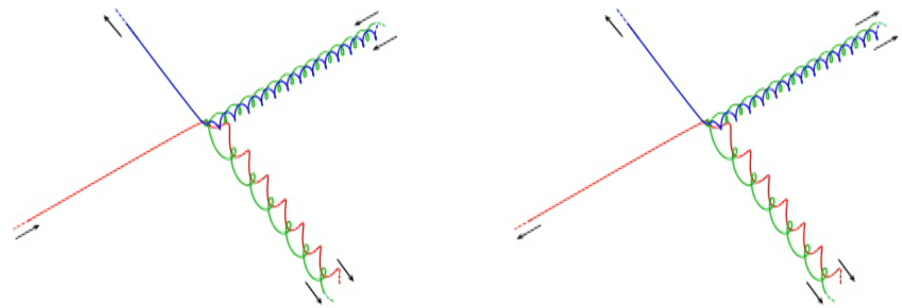
If $\boxed{E_{\text{cm}} \geq 0}$, then because $\boxed{V_{\text{New}} < 0}$ and $\boxed{k = -1}$ we have $\boxed{\ddot{I}_{\text{cm}} > 0}$

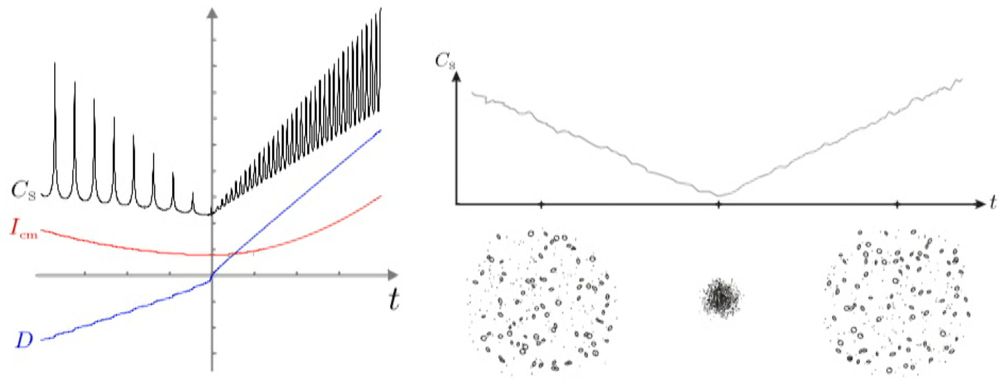
The moment of inertia is U-shaped upwards, the dilatational momentum $D = \sum_a \mathbf{r}_a \cdot \mathbf{p}^a \quad (= \frac{1}{2}\dot{I}_{\text{cm}})$ is monotonic and vanishes once.

$\boxed{\text{D=0 is a Janus point.}}$

It exists for all N-body solutions with non-negative energy.
First qualitative result in dynamics (Lagrange 1772)
but until 2014 never related to 'arrow-of-time' problem.
Only Cauchy problems, not complete solutions, considered.

0.4 The Relational 3-Body (Planar) & 1000-Body Problems





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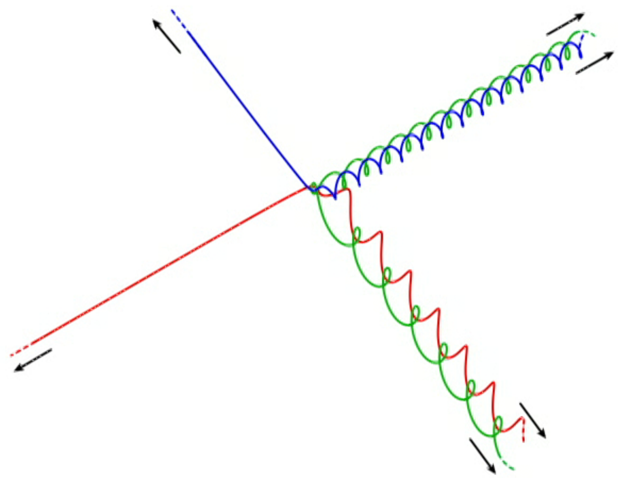
1.1 Origin of chronology, rods, clocks and frames



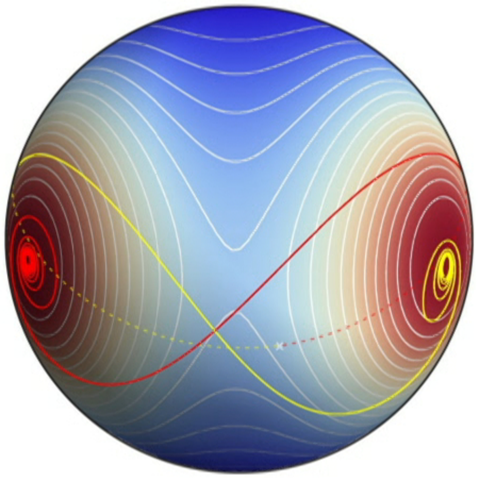
Each diagonal is a history that begins in the central Janus-point region from which pair and singleton emerge (arrows!). Time from 'big-bang' measured by periods of emergent Kepler pair, which also defines distance and direction.

In each N-body history, the 'universe' expands and breaks up into clusters.

Gravity creates structure out of chaos. For internal observers, only sensible choice for direction of time fixed by growth of structure, information and records (orbital elements stabilize ever better).

1.2 Emergence of Scale and Duration from Shape Curve

Newtonian solutions map many-to-one onto Shape Space. Even if $E_{\text{cm}} = \mathbf{L} = 0$ no direct encoding of $T_{\text{dil}}/T_{\text{tot}}$ on S.

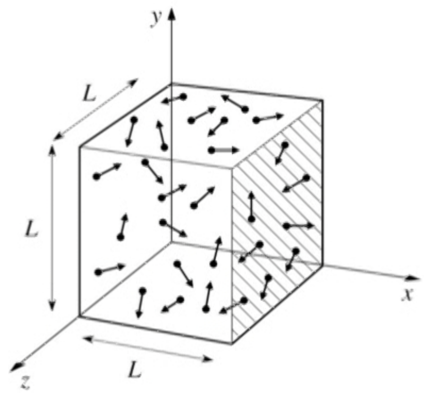


Find autonomous shape-space curve in terms of point, direction and curvature & specify scale (I_{cm}) at one point $\Rightarrow$ scale at all points found by quadrature. Specify second point to define unit of time $\Rightarrow$ duration found as ephemeris time at all points. Confirm shape-space curve passes smoothly through 'big-bang' singularities.

A useful paper that would complete Machian particle dynamics.

2.1 Boxes and the Origin of the Second Law

Ideal gas in a box



Box permits controlled supply and extraction of heat; measurement of pressure P, volume V and temperature T in equilibrium; and thus determination of entropy:

$$\mathrm{d}S = \frac{\mathrm{d}Q}{T}$$

Gibbs: Definition of entropy meaningful only for a system with compact phase space.

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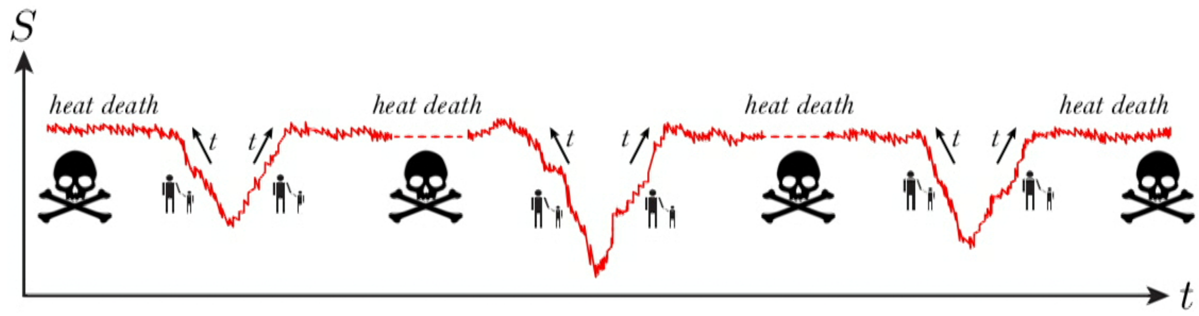
2.2 Poincaré Recurrences & Boltzmann's Conjecture

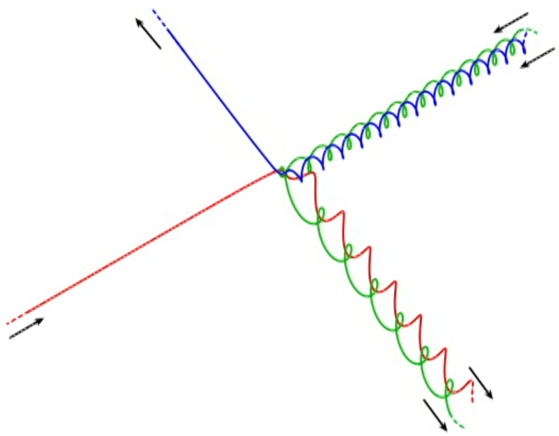
Free expansion 'thwarted' $\Rightarrow$ equilibrium and infinitely many Poincaré recurrrences. Solutions are qualitatively time-reversal symmetric.

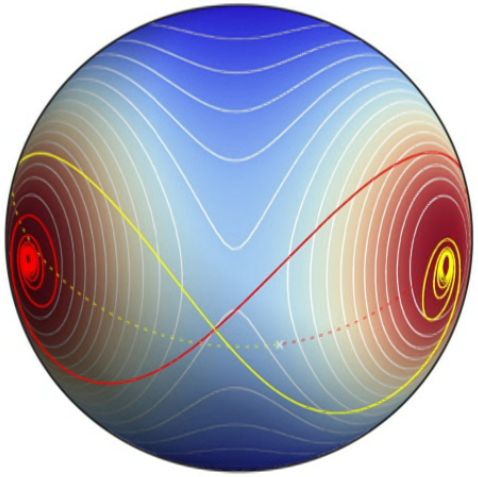


Boltzmann: "The universe is, and rests forever, in thermal equilibrium." Only near deep entropy dips "are worlds where visible motion and life exist . . . the direction of time towards the more improbable state [will be called] the past." This is a one-past–two-futures interpretation of each improbable state.

Boltzmann: Second Law is due to huge fluctuation in our remote past.
Today: Big Bang must have had an exceptionally low entropy.

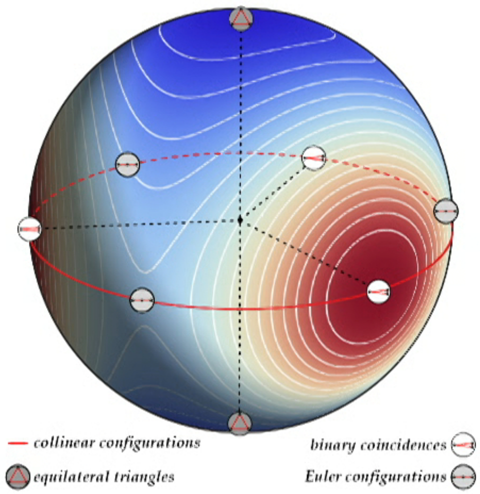
2.3 Liouville's Theorem, Attractors on S and the 2nd Law

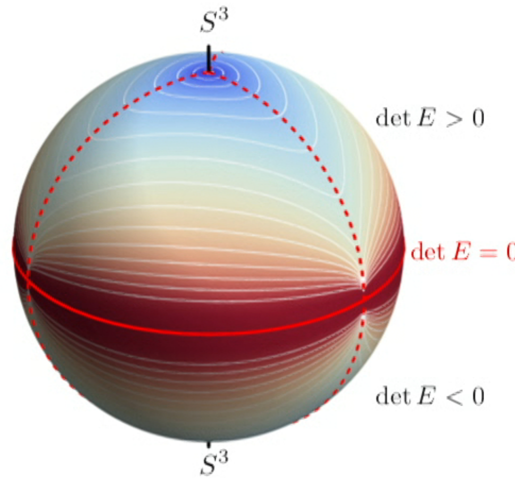




Liouville's theorem holds in extended phase space. If scale part of Gibbs phase expands, shape part must contract. Attractors + gravity ⇒ isolated clusters form ⇒ emergent Second Law in typical solutions. Incipient cluster virializes ⇒ increases Boltzmann entropy ⇒ Poincaré recurrences ⇒ decay (like radioactive particles). Needs sharpening.

3. Passage through Newtonian & Einsteinian Singularities



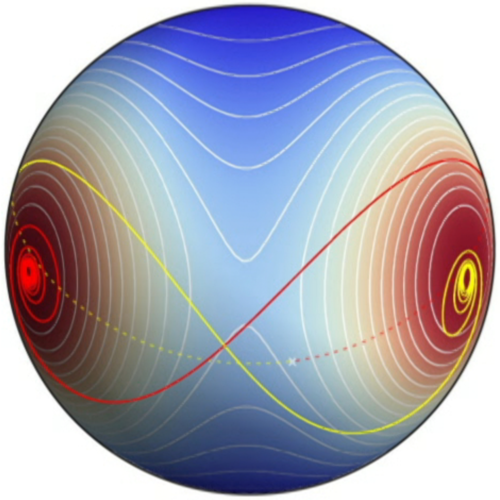


T Koslowski, F Mercati, and D Sloan, “Relationism Evolves the Universe through the Big Bang”, arXiv: 1607.02460v2.

BKL Conjecture suggests quiescent Bianchi IX at each space point.

4.1 Janus-Point Data & Typicality of Universes

Any entropy-like quantity must be a count of microstates in a phase-space region of bounded-measure defined by a state function. Mere monotonic increase does not make an entropy.



State functions and measures must be scale-invariant (no external rods & clocks). Complete solution set defined by point and direction at D=0. Non-redundant scale-invariant data and unbiased measure on Shape Space. Three-body configurational 'entropy' (entaxy) proportional to length of contour and *decreases*.

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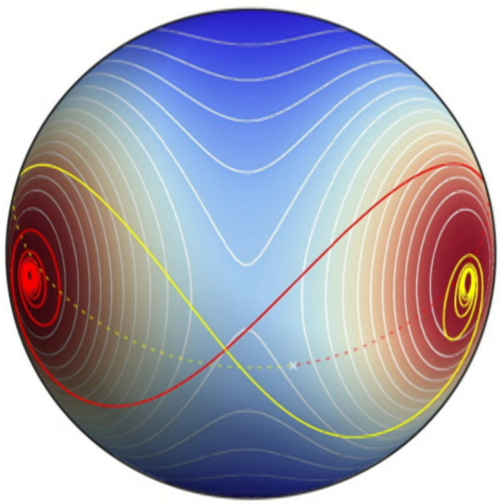

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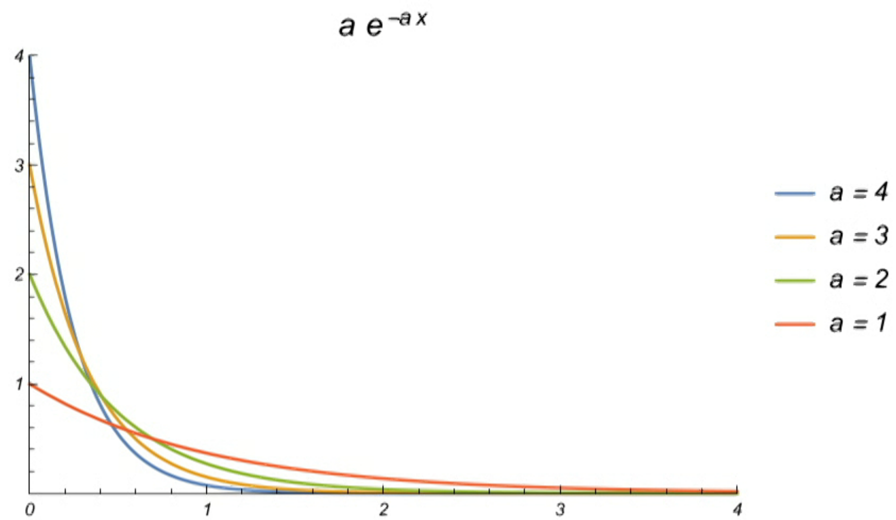
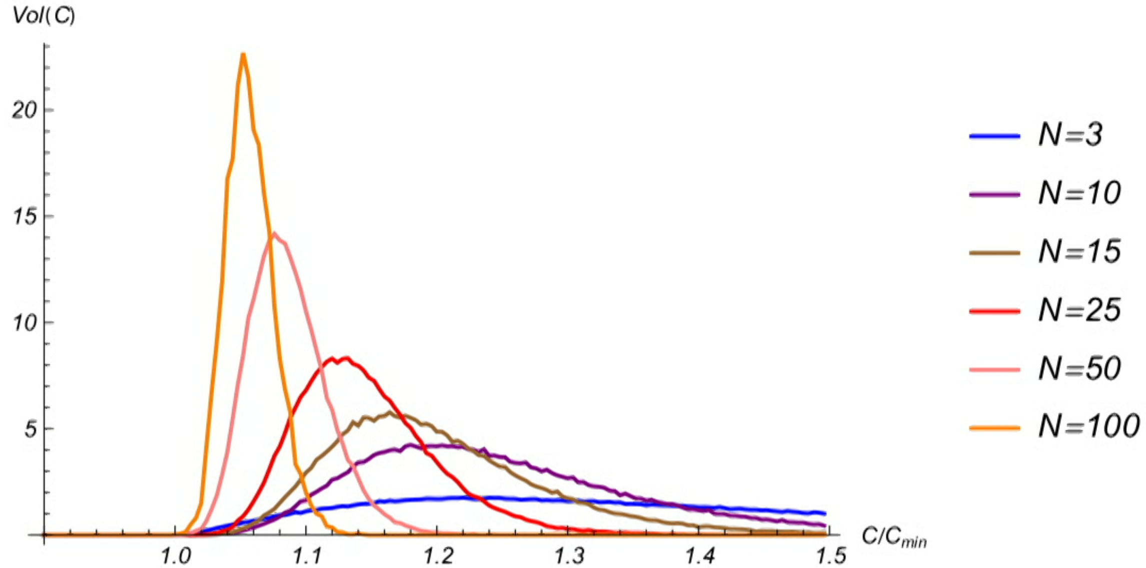
4.4 Normalized Momentum Distribution?



Is there a scale-invariant ‘Maxwell’ distribution?

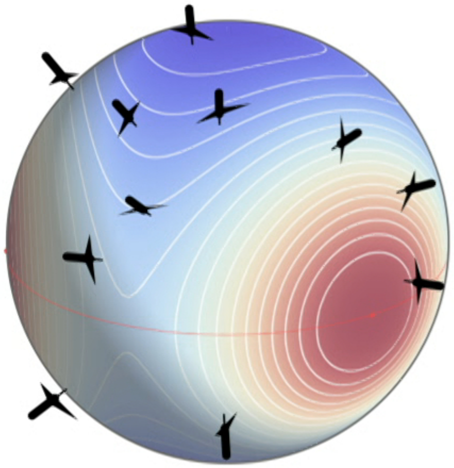
4.2 Shape-Space Volume vs. Complexity



Measure of shape macrostates as function of $C_{\text{S}}/C_{\text{min}}$. Sampling caveat but suggests typical universes will be very uniform at the Janus point.

4.3 ‘Blindfolded Creator’ Throwing Darts at S

We know the law of the universe. Can we predict nature of typical solutions? Laplace’s Principle of Indifference: if a certain number of outcomes are possible but nothing else known, give equal probability to each (GHS).



For large N, Laplace’s Principle suggests very uniform configurations and equally probable directions at Janus Point (strong prediction of Copernican Principle). Two problems: 1. Infinite number of degrees of freedom. 2. Distribution of normalized momenta and emergence of their magnitudes.

5.1 Quantum Gravity and Representation of Shapes

Attraction of Spatially Closed Universe:
Circle of mechanical causes and effects closes.

Question: Is quantum gravity local (spin networks)
or global (spherical harmonics)?

Possible advantage of Yamabe gauge, especially near big bang.