The New Science of Cryodynamics and Its Connection to Cosmology

Otto E. Rössler

Institute for Physical and Theoretical Chemistry
University of Tubingen
Auf der Morgenstelle A, 72076 Tubingen, Germany

A new science called cryodynamics is proposed as a physical discipline as fundamental as thermodynamics. It is based on work by Zwicky and Chandrasekhar and very recent numerical experiments on dynamical friction. It should be noted that most of the features of cryodynamics remain to be discovered yet; for instance, there is no entropy-like macroscopic function to be expected. Moreover, the combination of cryodynamics with thermodynamics is bound to lead to new insights. In other words, old-grained interpretations can be expected to give rise to a new synthesis. In addition, making a significant link between cryodynamics and cosmology is another fundamental aim of this work.

1. Introduction

The historical origin of modern chaos theory—the three-body problem—is still fertile. A never-before observed type of dynamical behavior—anti-dissipation in the forward direction of time—was numerically discovered recently [1]. An attempt to put the new phenomenon into perspective is made in the following.

2. Origins

A new science is never new. In the present case, some important features were already discovered by Lynden-Bell in a very complicated hybrid context [2]. The pure case goes back to Fritz Zwicky [3]. Zwicky coined the term "dynamical friction" in 1929 to explain the newly discovered Hubble phenomenon in cosmology: that light is losing energy on its way through the cosmos. Fourteen years later, Subrahmanyan Chandrasekhar confirmed Zwicky's intuition in a noncosmological context (the dynamics of globular star clusters), using 45 stochastic equations to demonstrate the existence of dynamical friction and to calculate its strength [4].

The paper [4] does not quote Zwicky. The latter had been refuted by Chandrasekhar's mentor Eddington for having made a calculating error. Zwicky had erroneously assumed that the galaxies in the cos-

mos were stationary, in which case the phenomenon disappears, as Zwicky acknowledged quoting Eddington's personal letter to him [5]. Chandrasekhar nevertheless succeeded in proving dynamical friction, or braking-at-a-distance, to be a reality for the very fast-moving stars that get ejected from the dense center of a globular cluster in a triple "almost-collision," thereby for the first time explaining the unique stability of these (as we know today) oldest visible structures of the cosmos.

Was Zwicky's intuition about a stationary, potentially infinitely old cosmos indeed justified? If dynamical friction is the opposite of entropy production in thermodynamics, as is the case shown in the following, a whole new picture of physics in the large arises.

3. The Need for Numerical Confirmation

The stochastic equations of Chandrasekhar [4] are well accepted in modern galactic dynamics [6]. Nevertheless, his equations are commonly believed to prove dynamical friction (i.e., a slowing-down of fast particles by their gravitational interaction with slower-moving particles) exclusively for fast-moving particles of the same or larger mass traversing a gas of gravitating particles (stars or galaxies, say), but not for much lower-mass particles like moonlets, rocks, or others of similarly high velocity [6]. The reason has to do with the continued belief in the general existence of a Maxwellian velocity distribution under attractive conditions even though counterexamples are acknowledged to exist [6]. This belief notwithstanding, Chandra's exceptional meticulousness led him to also calculate the friction coefficients for very low-mass objects without remarking on the implied violation of Maxwellicity.

This surprising connection (first pointed out to me by R. Movassagh, personal communication, 2006) went unnoticed for many decades. But the more important question is, of course: was Chandra right at all? Note that globular star clusters are not a very familiar paradigm in physics, nor are stochastic diffusion equations a frequently employed tool. In other words: is there a more solid basis for dynamical friction than that provided in Chandra's paper despite its greatness? In modern times, we have the option of numerical confirmation.

4. Is a Deterministic Model for Dynamical Friction Possible?

At first sight, the very idea appears highly doubtful. Suppose it was true that randomly moving Newtonian attraction centers drain kinetic energy away from passing lower-mass particles on a statistical basis.

Then this would mean that a time reversal causes the very same trajectories to show the opposite dynamical behavior. Thus, two types of initial conditions would need to exist in such celestial-mechanical systems: those generating dynamical friction in both directions of time (since we did not specify this direction in the first place), and those that do not because they first have to return to their initial point in the new direction of time. Such counterintuitive behavior has so far been known only from many-particle statistical mechanics in the context of dissipative behavior.

So it is quite surprising that two research groups seriously embarked on the problem, my student F. Grond in Tubingen in 2005, and my friends J. Kozak and J. Brezinski in Chicago three years later. Apart from a lack of funding that only enabled a stab at the problem, the model system chosen (two heavy slow and one light fast particle in a plane with periodic boundary conditions) did not reveal any clear-cut result. This negative outcome was in accord with the familiar million-particle simulations done in numerical cosmological modeling, which apparently never revealed similar properties.

5. A First Successful Scenario

Reducing the number of particles from three to two (by putting the third into an infinite-mass constraint) and halving the number of variables by reducing the number of space dimensions from two to one, proved helpful. In addition, a highly accurate symplectic simulation algorithm of the fourth order (arguably the best universal algorithm for general Hamiltonian systems), newly written from first principles, was chosen [1].

The two particles were allowed to move in a T-tube configuration without ever touching: each shuttling back and forth in one dimension either vertically or horizontally, but both coupled by a Newtonian potential acting between them in two dimensions. The masses of the two particles were chosen to differ strongly, and so did their speeds whereby the fast low-mass horizontal particle possessed much less kinetic energy [1].

The existence of dynamical friction could be confirmed in all (about 10) different long-term simulations fulfilling the mass and velocity criteria. That is, the heavy slow particle extracted kinetic energy on average from the light fast particle. Hereby indeed two classes of initial conditions exist: nonselected ("virgin") ones that showed the same qualitative behavior in both directions of time, and "committed" ones that after a time reversal first traced back the previous motion before showing the old behavior of dynamical friction in the new direction of time.

The finding still awaits confirmation by other groups. Thus, the whole terrain still represents virgin territory. In addition, it must be noted that the simulations invariably showed the described behavior

only over finite (rather long) times before running into a numerical artifact: a high-periodicity periodic motion that was no longer chaotic. This is obviously a numerical approximation to a thin Kolmogorov–Arnold–Moser (KAM) torus embedded in the chaotic phase space. By further adding one or more light particles, this problem can most likely be overcome (albeit at the expense of losing the maximum simplicity of the two-particle system).

Thus, the numerical prototype model is far from exhausted. Apart from adding more particles, there is also the opposite option: reduce the number of variables still further by continuing to increase the mass of the heavy particle while simultaneously reducing the coupling coefficient G. Then in the end, a simple periodically forced chaotic Hamiltonian oscillator in one space dimension—the standard model of chaos theory since Poincaré—would be all that remains to analyze further. In this case, cryodynamics will be a straightforward implication of Hamiltonian chaos theory. And so, of course, will be thermodynamics in the corresponding repulsive case under the same condition. Whether a single forced oscillator suffices is an open question.

6. Fundamental Implications

The numerical breakthrough achieved by Sonnleitner [1] deserves confirmation and elaboration. The new behavior found is not the only surprise. Inverting the potential analogously revealed the essential feature of thermodynamics—dissipation—for the first time in a simple deterministic setting. Boltzmann would be delighted. Imagine: deterministic chaos at the basis of two physical disciplines, one venerable, the other (obtained by a sign flip) so new as to be almost nonexistent—thermodynamics and cryodynamics.

If the described work is allowed to go on (no funding is in sight), a few predictions can already be ventured. First, cryodynamics will become the new fashion on the block. A whole new fundamental discipline in physics since thermodynamics, after a pause of 150 years, is a bonanza—even without cosmology waiting to profit. Many other disciplines are bound to be fertilized.

How will the Sackur–Tetrode equation of statistical thermodynamics look in the new setting? (The latter was implicated in the origin of quantum mechanics [7].) How will the cousin of entropy look? How about the analog to Diebner's deterministic classical entropy [8]?

7. Life 2.0?

If life is a refined method for putting an obstacle into energy dissipation by letting a roundabout way become more and more elaborate, can perhaps something similar occur much more directly under

the new anti-dissipative time's arrow? For in this case, "complexification" would not be a secondary effect but rather the main feature, much like heat death is in the older case. Teilhard's "point omega" would then acquire a more direct and hence possibly more powerful twin.

Is the cosmos at large alive? Such a strange question would have been impossible to raise as a falsifiable scientific hypothesis before the discovery of cryodynamics.

8. Cryodynamics and Cosmology

Historically, cosmology lies at the origin of dynamical friction and hence of cryodynamics. Hubble was denied his Nobel Prize for not disguising his sympathy to Zwicky's idea of "tired light," which remained a laughingstock for many decades to come. In the absence of the new statistical-mechanical paradigm of cryodynamics, no possible chance of seeing an alternative to the Western "linear" cosmological paradigm with its maximally unlikely initial state existed. The twentieth century's embracing of a bomb at the beginning belied both Boltzmann and Saint Augustine. Nevertheless, a recourse to Friedmann's early expanding special solution of the Einstein equation, at the expense of many other equally eligible solutions (including that of a flat unbounded static universe of unit fractal dimensionality), remained the only reasonably available option for almost a century. Hubble's spectacular cosmological red shift left no other choice at the time (unless, that is, Chandra had quoted Zwicky in which case history might have taken a different turn, but this is a "variantological speculation" in the sense of S. Zielinski).

The eight intervening decades provided ample room to accommodate a time-asymmetric cosmology—despite many efforts made by deep thinking physicists to get around the origin problem—most prominently among them R. Penrose [9]. The two opposite disciplines of particle physics and cosmology have over the years effectively merged into the single discipline of astrophysics, which no longer lets cosmology appear as a weaker field of its own notwithstanding its incapability to allow for experimentation.

Is it possible that the most popular scientific theory ever, the "big bang," is in for a total overhaul owing to the discovery of cryodynamics? The answer appears to be clear-cut. The modern cosmological standard model comprises an impressive list of accepted scientific "facts": big bang, inflation, primordial nucleosynthesis, cosmological origin of the microwave background radiation, accelerated expansion, dark energy, nonbaryonic dark matter, 13.7 billion years of cosmic age, 4 percent baryonic mass, baby universes, and others. This success story appears irreversible since over the decades, the standard model of the cosmos automatically acquired numerous links to the other

standard model of particle physics as mentioned, so that a famous particle accelerator can be seriously referred to as a "big bang machine."

9. The Two Hardest Points

Cryodynamics is such a major addition to physics that "almost everything" appears to be in need of an overhaul in its wake provided Chandrasekhar dynamical friction can be confirmed for lightweight particles. Nevertheless, two elements in the cosmological standard model appear especially "hard" in the sense of being virtually irreplaceable: (*i*) the "cosmological background radiation" and (*ii*) the "primordial nucleosynthesis." These two immutable pillars of the standard model of cosmology throw grave doubts on the cosmological relevance of cryodynamics. A peaceful coexistence is almost more than can be hoped for, it appears.

Luckily, most recently the cosmic background radiation, together with many other types of radiation and frequency ranges, has been measured anew in a big astrophysical project (Planck Mission). Hot dark matter in the galactic background appeared to merge smoothly with the ubiquitous microwave background. Fraunhofer spectra offer themselves for a detailed comparison of the red shifts as far as systematic angular shifts are involved for both types of radiation. If there were no Hubble expansion, both types of radiation would have to be strongly red shift-correlated in the lowest spatial frequency component reflecting the Earth's movement with the sun in the galaxy.

A second crucial empirical test point needs to be mentioned. Several years ago, Nobel laureate R. Giacconi discovered many equidistributed maximally weak X-ray point sources in the sky, the photons of which come trickling in at a rate of only one per hour or less. Measuring the red shift of these putative maximally distant "X-ray quasars" is bound to take many years. Whether the measuring program is still being continued, six years after Giacconi's pertinent talk given at the University of Tubingen, is hard to find out at the time being. This measurement, too, could provide for an instant clarification of the big open issue on hand.

10. A Third Counterargument

A third important counterargument to our cosmos being potentially very old is black holes. Suppose the cosmos were nonexpanding and potentially infinite in extension (if its fractal dimensionality is close to unity not only in the easily visible part): would the cosmos then not have to be "dead," that is, made up of black hole matter only, for a very long time already?

Here again an open, but soluble, question exists. Black hole theory is more difficult than has been thought for a long time. If black holes are never finished, as first noted in [10], the merger of two "almost finished" black holes possesses radically different properties than currently thought. The field is very much in flux at the moment. A scenario in which the smaller unfinished black hole is totally shredded and re-ejected in the form of elementary particles is a possibility that may be worth taking seriously since every in-falling particle headed for the smaller black hole will have to be re-directed toward the larger one at some point in time—but at this point, its trajectory is bound to cross (and therefore momentarily coincide with) the unstable manifold of a saddle point forming between the two gravitational attractors. This conjecture is pure speculation at the time being but mathematically decidable. Thus, at the current moment in time, the three most convincing cosmological counterarguments against a cryodynamic cosmology appear to be open.

11. Discussion

A synoptic view on a currently emerging new fundamental physical science—cryodynamics—has been attempted. Its historical origins lie in astronomy, with Zwicky and Chandrasekhar as the great innovators. Nevertheless, cryodynamics (*cryós* means "cold" in Greek just as *thermós* means "hot") is still absolutely "virgin" in the sense that almost all of its properties remain to be discovered. So, we have all been catapulted back to the time of Maxwell and Clausius as it were.

Sonnleitner's dissertation marks the breakthrough that propels dynamical friction from the rank of a curiosity in galactic modeling to that of being the basis of a new fundamental science no lower in rank than thermodynamics itself. Surprisingly, both cryodynamics and thermodynamics (the latter here with an unusual potential) turn out to be implications of the Newton–Einstein theory and, at the same time, straightforward implications of chaos theory. Now the scientific world is waiting to find out how the new science is going to develop since a first independent confirmation has yet to come in.

Cosmology is but one field of application. Experiment—on Earth—is another. Fast electrons shot through a positively charged plasma in an Iter-like experiment could provide a test bed. The prediction is that the electrons will be braked, thereby further heating up the plasma. A very acidic dilute hot gas could provide a simpler experimental alternative. Fast electrons can be shot in and visibly be kept on a circular course by using a magnetic field. This allows monitoring a systematic cooling effect if the visible circulation radius of the fast electrons decreases in this modified Kaufmann experiment.

To conclude, it appears that a meticulous numerical experiment brought on a new paradigm. Nevertheless, it is presently an open question whether cryodynamics can pay back to cosmology what it owes to it. At any rate, a new type of dynamical thinking—deterministic-chaos based—has invaded statistical physics. Following decades dominated by quantum mechanics, a more old-fashioned thinking harking back to the founding fathers is palpable. New experimental surprises are in store. Eventually, if the basic idea is sound, the discovery of many quantum applications will mark the transition to the second, more mature phase of cryodynamics.

Acknowledgments

This paper is dedicated to Roger Penrose on the occasion of his 80th birthday. I thank Ali Sanayei, Klaus Sonnleitner, Frank Kuske, Dieter Fröhlich, Thimo Böhl, Stu Kauffman, Siegfried Zielinski, Christophe Letellier, Jürgen Parisi, Renzo Ricca, Dan Stein, and Nils Schopohl for discussions. For J.O.R.

References

[1] K. Sonnleitner, "StV4: Ein symplektisches zeitreversibles Störmer–Verlet-Verfahren vierter Ordnung für Hamiltonsche Mehrteilchensysteme mit zwei Anwendungsbeispielen (Gas, T-Rohr-Anordnung)," Ph.D. dissertation, 2010. http://www.wissensnavigator.com/documents/StV4-universell.pdf.

[2] D. Lynden-Bell and R. Wood, "The Gravo-Thermal Catastrophe in Isothermal Spheres and the Onset of Red-Giant Structure for Stellar Systems," *Monthly Notices of the Royal Astronomical Society*, **138**, 1968 pp. 495–525.

[3] F. Zwicky, "On the Red Shift of Spectral Lines through Interstellar Space," *Proceedings of the National Academy of Science*, **15**(10), 1919 pp. 773–779. http://www.pnas.org/content/15/10/773.full.pdf+html.

[4] S. Chandrasekhar, "Dynamical Friction. I. General Considerations: The Coefficient of Dynamical Friction," *Astrophysical Journal*, **97**, 1943 pp. 255–262.

[5] F. Zwicky, "On the Possibilities of a Gravitational Drag of Light," *Physical Review*, **34**, 1929 pp. 1623–1624. http://authors.library.caltech.edu/5559/1/ZWIpr29.pdf.

[6] J. Binney and S. Tremaine, *Galactic Dynamics*, Princeton, NJ: Princeton University Press, 1987, second edition 2008.

[7] O. E. Rössler, "An Estimate of Planck's Constant," in *Dynamic Phenomena in Neurochemistry and Neurophysics: Theoretical Aspects (ESN '85)*, Budapest, Hungary (P. Erdi, ed.), 1985 pp. 16–18.

[8] H. H. Diebner and O. E. Rössler, "A Deterministic Entropy to Monitor the Evolution of Microscopically Simulated Far-From-Equilibrium Structures," *Chaos, Solitons and Fractals*, **19**(4), 2004 pp. 699–703.

[9] R. Penrose, *The Road to Reality. A Complete Guide to the Laws of the Universe*, New York: A. A. Knopf, 2005.

[10] O. E. Rössler, H. Kuypers, H. H. Diebner, and M. S. El Naschie, "Almost-Black-Holes: An Old-New Paradigm," *Chaos, Solitons and Fractals*, **9**(7), 1998 pp. 1025–1034. http://www.scribd.com/doc/36300365/Almost-Black-Holes-an-Old-New-Paradigm.