Dissipative physics?

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Theoretical Physics Seminar

20 November 2026

Outline

I. Ideal and dissipative

- the laws of ideal and real worlds
- dissipation-free, reversible, time-reversal invariant
- time reversal is not covariant

II. Thermodynamics as stability

- universality
- stability: bodies and continua
- constructive use: entropy balance, Liu procedure
- qualitative predictions: classical holography, dissipative momentum

III. Strategy and consequences

- Newton's dynamical law and the experiment
- Newtonian gravity, galactic rotation curves
- quantum fluids
- back to irreversibility; open questions

The question of the title: are the fundamental laws ideal, with dissipation as a correction, or is the dissipative world the starting point and ideality its special limiting case?

The laws of ideal and real worlds

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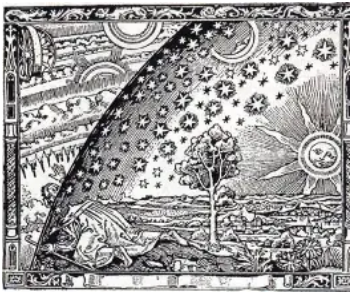

Wood engraving from C. Flammarion, *L'atmosphère* (1888): the traveller reaches through the vault of the sky. Below: change and decay; beyond: the perfect, eternal heavens. The ideal laws came from there.

In almost every discipline the fundamental laws are ideal: only dissipation-free, reversible, time-reversal invariant evolution equations are regarded as fundamental, and the world is explained with them.

The usual view of dissipation: an effective phenomenon of averaged, coarse-grained microdynamics.

The difficulty: dissipation cannot be explained with ideal concepts alone. Which parameter must have a definite sign? One first needs a theory that *defines* dissipation.

Nonequilibrium thermodynamics

The starting point is the dissipative world. A perfect system is a marginal imperfect one.

Old questions

- Where do the dissipative evolution equations of physics come from? How can they be derived?
- How should the second law be understood: mathematically and constructively?

Confused concepts, surprising clarification

published manuscript

Dissipation-free

Dissipation is measured by the **entropy production**. This is meaningful only if the variables that determine the evolution are thermodynamic state variables.

Extensions of an ideal equation are of three kinds: ideal, dissipative, and impossible (unphysical, often unstable).

Reversible

A physical law is a set of differential equations; its **processes** are the solutions.

A process is reversible if its time-reversed version is also a process of the law.

A law is reversible if all of its processes are reversible.

Time-reversal invariant

Reversibility of a law = invariance under time reversal.

This needs a correct definition of time reversal in space-time.

The usual formula is not covariant (next slide).

In thermodynamics the ideal, reversible case is the marginal one: zero entropy production.

Ván, J. Non-Equilib. Thermodyn. 51, 633 (2026); T. Matolcsi, Microscopic irreversibility, manuscript (2026)

Time reversal is not covariant

manuscript derived

The usual formula $T(t,\mathbf{q}) := (-t,\mathbf{q})$

- reverses time about a zero point that does not exist
- refers to one reference frame. In coordinates ($c=1$, one space dimension), for a frame moving with velocity v:

$$L_v:\ (t,x)\mapsto \gamma\,(t-vx,\ x-vt), \qquad \gamma=(1-v^2)^{-1/2}$$

$$L_vT\,(t,x)=\gamma\,(-t-vx,\ x+vt)$$
$$T'L_v\,(t,x)=\gamma\,(-t+vx,\ x-vt)$$
$$\boxed{L_vT=T'L_{-v}\neq T'L_v}$$

- the time reversals of different inertial frames are different maps of space-time; a function invariant under all of them is constant

The usual time reversal is neither Lorentz nor Galilei covariant.

Correct definition: for every space-time point o and four-velocity u

$$T_{(u,o)}(x) := x + 2\Big(u\cdot(x-o)\Big)\,u$$

Consequences

- Maxwell equations: time-reversal invariant only without sources
- Newton equation $m\ddot{r}=f(r,\dot{r})$: only for $f=0$ (calculation: backup)
- only the *free* equations are time-reversal invariant

Force and source are prescribed here: actions, not interactions. The closed particle–field system: next slide.

Is there a general mechanism of irreversibility?

manuscript open

Starting point. The equations of mechanics and of electromagnetism treat *actions* instead of *interactions*. For the particle–field interaction there is, at present, no equation, either in classical or in quantum theory.

Why emission and absorption are not symmetric

- **emission needs only the particle:** an accelerated charge or an excited atom radiates by itself (spontaneous emission)
- **absorption needs the field:** radiation of the right frequency must arrive; there is no spontaneous absorption
- the emitted radiation spreads in all directions and leaves; the reversed process, a wave converging exactly onto the particle, does not occur by itself

Thesis (T. Matolcsi)

Irreversibility can be the consequence of particle–field interaction, based on the asymmetry of emission and absorption.

Hypothesis: irreversibility is fundamentally built in Nature, also at the microscopic level.

Consequences

- probabilities are needed because of our lack of knowledge about the particle–field interaction, not because 10^{24} differential equations cannot be solved
- the contradiction between microscopic reversibility and macroscopic irreversibility disappears

T. Matolcsi, Microscopic irreversibility, manuscript (2026)

Universality: what does not depend on the material

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Universal = independent of material and microstructure

- free fall: weak equivalence principle (Eötvös–Pekár–Fekete)
- absolute temperature: efficiency of the reversible engine
- critical exponents of second-order phase transitions
- **fluid equations**: Navier–Stokes–Fourier is the same for very different fluids; the material enters only through the coefficients
- conservation laws, objectivity of physical laws

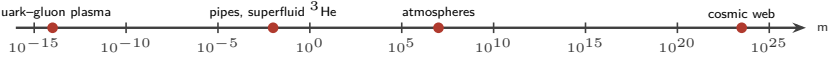
Thermodynamics $\neq$ statistical physics

- statistical physics: a more detailed micro-model
- thermodynamics: **more general** (rheology, internal variables) and **more universal** (black holes, quark–gluon plasma)

Question. Where does universality come from?

Thesis. Not from a statistical background but from the requirement of stable equilibrium: without it there are no reproducible experiments.

Fluids are everywhere:



Ván, Phil. Trans. R. Soc. A 381, 20220276 (2023); Ván, ELFT Vándorgyűlés talk (2025); Szücs–Ván, Phys. Fluids 38, 118116 (2026)

Thermodynamics is a stability theory

published derived

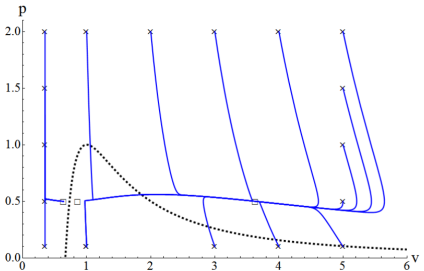
Ordinary thermodynamics (a dynamical system approach): a homogeneous body (E, V) in an environment (T_k, p_k)

$$\frac{\mathrm{d}E}{\mathrm{d}t} = -\alpha\,(T - T_k) - p\,\dot{V}, \qquad \frac{\mathrm{d}V}{\mathrm{d}t} = \beta\,(p - p_k)$$

Production of the total entropy ($Q = -\alpha(T - T_k)$, $F = \dot{V}$):

$$\dot{S}_T = Q\left(\frac{1}{T} - \frac{1}{T_k}\right) + \frac{F}{T_k}(p - p_k) \geq 0 \;\Rightarrow\; \alpha, \beta \geq 0$$

Concave $S(E, V)$ + non-negative production = the conditions of Lyapunov's theorem: the total entropy is a Lyapunov function of the equilibrium.



Processes of a Van der Waals body in the (v, p) plane tend to equilibrium.

Continua: the linear stability of the homogeneous equilibrium is the necessary condition and the benchmark of the method.

Matolcsi, Ordinary Thermodynamics (2005);Haddad–Chellaboina (2009); Ván, Phil. Trans. R. Soc. A 381, 20220276 (2023); Ván, ELFT talk (2025)

What about continua?

published

Thermodynamic stability structure

- entropy is a potential on the state space,
- it is concave (thermodynamic stability),
- it increases in an isolated system.

These are exactly the conditions of Lyapunov's theorem for the asymptotic stability of equilibrium.

Fundamental dynamic stability (FDS): the homogeneous equilibrium is stable under thermodynamic conditions alone.

Navier–Stokes: viscosity damps the kinetic energy, the tendency to homogeneous equilibrium is physically evident. Open (Clay Millennium problem): do the gradients stay bounded on the way?

theory	FDS
ordinary thermodynamics (thermostatics)	**OK**
Fourier–Navier–Stokes, 1st order	**OK**
MCV–Navier–Stokes, truncated 2nd order	**OK?**
ballistic heat conduction, 3rd order	**OK**
Korteweg fluids	**OK?**
Eckart, relativistic 1st order	**NOT**
Israel–Stewart, relativistic 2nd order	**OK?**
BDNK, relativistic	**OK?**

Further stability problems: runaway solutions of the Lorentz–Abraham–Dirac equation; Jeans instability (a genuine physical instability), Bobylev instability.

Table after Fig. 1 of Somogyfoki et al., J. Non-Equilib. Thermodyn. 50, 59 (2025), Leray, Acta Math. 63, 193 (1934)

Constructive use I: the entropy balance

published derived

Calculation of the entropy production (Eckart, 1940)

$$\varrho\dot{e} + \nabla\cdot\,\mathbf{q} = 0, \qquad \mathrm{d}e = T\,\mathrm{d}s$$

$$\varrho\dot{s} + \nabla\cdot\left(\frac{\mathbf{q}}{T}\right) = \frac{\varrho\dot{e}}{T} + \nabla\cdot\left(\frac{\mathbf{q}}{T}\right) = \mathbf{q}\cdot\nabla\frac{1}{T} \geq 0$$

Solution of the inequality

$$\mathbf{q} = \lambda_{th}\nabla\frac{1}{T} = -\lambda_F\nabla T, \qquad \lambda_F = \frac{\lambda_{th}}{T^2} \geq 0$$

Ingredients

- space-time: comoving time derivative, constitutive state space, balances
- thermostatics: specific entropy is a local potential
- entropy production: thermodynamic force $\times$ flux

Universal: the structure of the equation.
Material: $e = cT$, $\lambda_F(e)$.

Eckart, Phys. Rev. 58, 267 (1940)

Constructive use II: Liu procedure and weak nonlocality

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The entropy inequality is conditional: balances, evolution equations (*and their gradients*) are constraints, handled by Lagrange–Farkas multipliers.

E.g. a constitutive state space of the fluid with a scalar internal variable φ ($\dot{\varphi} + f = 0$):

$$(\varrho, \nabla\varrho, \nabla^2\varrho,\ \mathbf{v}, \nabla\mathbf{v},\ e, \nabla e,\ \varphi, \nabla\varphi, \nabla^2\varphi)$$

Constitutive functions: $\mathbf{P},\ \mathbf{J}_E,\ f,\ s,\ \mathbf{J}_S$.

$$\varrho\dot{s} + \nabla\cdot\mathbf{J}_S - \sum_a \Gamma_a\,(\text{constraint})_a\ \geq 0$$

Liu equations $\Rightarrow$ reduced state space of the entropy:

$$s = s(\varrho, \nabla\varrho, \mathbf{v}, e, \varphi, \nabla\varphi)$$

Results

- the constitutive entropy current $\mathbf{J}_S$ is determined, not postulated
- entropy production = thermal + internal-variable + mechanical terms
- **functional derivatives without a variational principle:**

$$\frac{\delta\varepsilon}{\delta\varrho} = \frac{\partial\varepsilon}{\partial\varrho} - \nabla\cdot\frac{\partial\varepsilon}{\partial(\nabla\varrho)}$$

Liu's theorem is a special case of the Farkas lemma (1895).
$\varepsilon(\varrho, \nabla\varrho, \varphi, \nabla\varphi)$: extra energy density.

Benchmark: heat conduction beyond Fourier

published derived tested

Third-order extended heat conduction (1D; state variables e, q, Q)

$$\tau_q \dot{q} + q - l_q^2 \, \partial_{xx} q + a_Q \, \partial_x Q = \lambda_{th} \, \partial_x \frac{1}{T}$$

$$\tau_Q \dot{Q} + Q - l_Q^2 \, \partial_{xx} Q + a_q \, \partial_x q = 0$$

- Fourier, Maxwell–Cattaneo–Vernotte, Guyer–Krumhansl, ballistic–conductive: special cases
- **beyond Extended Thermodynamics:** the diffusive terms (l_q, $l_Q \neq 0$) cannot appear there; $a_q \neq a_Q$ requires them
- **stability follows from thermodynamics** (theorem: backup)

Why a benchmark

- the evolution equation of the heat flux is constructed from the second law, without a microscopic model
- predicted, then measured: Guyer–Krumhansl-type heat conduction at room temperature in heterogeneous materials tested
- kinetic theory (Extended Thermodynamics) gives a special case only

Somogyfoki et al., J. Non-Equilib. Thermodyn. 50, 59 (2025), Eqs. (29)–(30); Both et al., JNET 41, 41 (2016); Ván et al., EPL 118, 50005 (2017)

Qualitative prediction: classical holography, entropic force

published derived

Definition. A perfect continuum is *classical holographic* if there is a scalar potential Φ with

$$\nabla\cdot\mathbf{P}_{\mathrm{per}} = \varrho\nabla\Phi \qquad \Longrightarrow \qquad \dot{\mathbf{v}} = -\nabla\Phi.$$

Surface forces are equivalent to a bulk force: field and mass-point descriptions coincide.

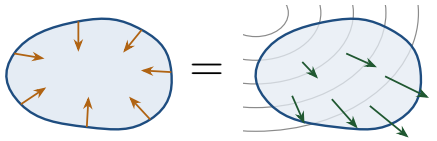
Result (zero dissipation, internal variable in equilibrium):

$$\nabla\cdot\mathbf{P}_{\mathrm{per}} = \varrho\nabla\Phi \quad\Longleftrightarrow\quad \boxed{\nabla s\times\nabla T = \mathbf{0}},$$

$$\Phi = h_{\mathrm{fl}} + \frac{\partial\varepsilon}{\partial\varrho} - \nabla\cdot\frac{\partial\varepsilon}{\partial(\nabla\varrho)} = h_{\mathrm{fl}} + \frac{\delta\varepsilon}{\delta\varrho} \quad \text{(homoentropic case)}.$$

The Korteweg, quantum and gravitational gradient terms are no obstruction; the only obstruction is thermal, already present for Euler fluids.

Perfect = holographic and variational ($\delta\varepsilon/\delta\varrho$ from the second law).



If the condition fails, the residual force is the **entropic force** $T\nabla s$; its curl is the baroclinic vorticity source.

The name refers to Gabor's optical holography, not to the holographic principle of quantum gravity.

Szücs–Ván, Phys. Fluids 38, 118116 (2026)

Qualitative prediction: dissipative momentum

published derived

Hypothesis. Position and momentum are thermodynamic state variables: $S(E,x,p) = \hat{S}\big(E - H(x,p)\big)$.

Unknown dynamics $\dot{x} = g_x$, $\dot{p} = g_p$; the second law at $\dot{E} = 0$:

$$\dot{S} = -\frac{1}{T}\big(\partial_x H\, g_x + \partial_p H\, g_p\big) \geq 0.$$

Linear solution

$$\begin{pmatrix}\dot{x}\\ \dot{p}\end{pmatrix} = -\left[\begin{pmatrix} l_1 & l\\ l & l_2\end{pmatrix} + \begin{pmatrix} 0 & k\\ -k & 0\end{pmatrix}\right]\begin{pmatrix}\partial_x H\\ \partial_p H\end{pmatrix}$$

with $l_1 \geq 0$, $l_2 \geq 0$, $l_1 l_2 - l^2 \geq 0$. Antisymmetric part: Hamiltonian evolution ($k = 1$); symmetric part: dissipation.

For $H = p^2/2m + V(x)$ the momentum is not proportional to the velocity:

$$p = \frac{m}{k-l}\big(\dot{x} + l_1 V'(x)\big).$$



l_1 has no counterpart in Newtonian mechanics. Experiments may decide.

Ván, J. Non-Equilib. Thermodyn. 51, 633 (2026)

Research strategy and tests

published

Could the second law of thermodynamics be a first principle? How to test it?

Strategy. The second law is a construction principle for evolution equations; ideal theories are the zero-dissipation limit of dissipative ones. Validation proceeds along two paths: **compatibility** with well-established theories and **tests focused on deviations**.

prediction	**Test 1: compatibility**	**Test 2: deviation-focused test**
classical holography	Euler, Korteweg, Schrödinger–Madelung fluids, Newtonian gravity as special cases	vorticity sources; modified gravity
fundamental dynamic stability	Fourier–Navier–Stokes; Fourier, MCV, Guyer–Krumhansl heat conduction	higher-order and relativistic theories
dissipative momentum	Newton equation, damped oscillator, Eliezer–Ford–O'Connell equation as limits	torsion pendulum with variable moment of inertia

The three predictions do not follow from the mechanical world view; the experiment on the dissipative momentum is the critical test.

Precedents: Einstein equation as an equation of state (Jacobson 1995); complete positivity and entropy inequalities (Lindblad 1975).

Szücs–Ván, Phys. Fluids 38, 118116 (2026); Ván, J. Non-Equilib. Thermodyn. 51, 633 (2026)

Newton's dynamical law: the dissipative equation of motion

published derived open

With the force $F = -V'$ and $\det L = l_1 l_2 - l^2 + k^2$:

$$m\ddot{x} - m\,l_1\dot{F} + l_2\,\dot{x} - \det L\,F = 0 \qquad \Longleftrightarrow \qquad m\ddot{x} = \det L\,F - (l_2 + l_1\,m\,V'')\,\dot{x}$$

case	equation ($k = 1$)	
$l_1 = l_2 = 0$	$m\ddot{x} = F$	Newton
$l_1 = 0$	$m\ddot{x} + l_2\dot{x} = F$	damped
$l_2 = 0$	$m\ddot{x} - m\,l_1\dot{F} = F$	EFO–Verhás

The new damping term couples to the inertial mass m *and* to the curvature V'' of the potential.

EFO–Verhás: the structure of the Eliezer–Ford–O'Connell equation of radiation reaction (no runaway solutions, unlike Lorentz–Abraham–Dirac), here without any electrodynamic input. Limiting acceleration (Price et al. 2022). The new term is not exotic, it was always there.

Structural parallels and examples

- **Metamechanics.** Complex effective mass tensor from hidden degrees of freedom (Milton–Willis 2007).
- **Quantum damped oscillator.** A completely positive (Lindblad) master equation requires a $[p, [p, \rho]]$ term absent from the Caldeira–Leggett equation. Caldeira–Leggett + dissipative momentum = Lindblad dynamics (Dekker 1977, 1981; Diósi 1993).
- **Fluid mechanics, $\mathbf{p} \neq \varrho\mathbf{v}$.** Bivelocity (Brenner 2005), self-diffusion, relativistic fluids (BDNK 2019, 2022).
- **Continuum mechanics:** rheology, inertial and relaxational evolution in one framework. *Proved:* dual internal variables, generalised continua.
- **Noncommutative mechanics.** Effective forces and velocity-dependent potential (Liang 2024, 2025). *Conjecture:* an ideal (antisymmetric) analogue of the l_1 term.

Ván, J. Non-Equilib. Thermodyn. 51, 633 (2026); Caldeira–Leggett (1983); Diósi (1993); Liang (2024, 2025); Ván, Thermodynamics 2.0 talk (2026)

Experiment I: prediction and principle

published derived

Damped oscillator, $V = Dx^2/2$:

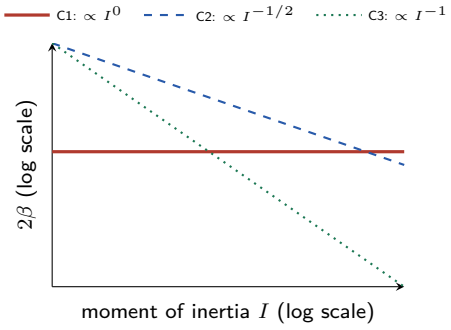
$$m\ddot{x} + (m\,D\,l_1 + l_2)\,\dot{x} + \det L\,D\,x = 0$$

The damping coefficient depends linearly on the inertia and on the spring constant.

Torsion pendulum: $I\ddot{\varphi} + c\,\dot{\varphi} + D\varphi = 0$, $2\beta = c/I$, $\omega_0^2 = D/I$

$$\boxed{2\beta = l_1 D + \frac{l_2}{I}}$$

- only a variable moment of inertia separates the channels
- second law: $l_1 \geq 0$, $l_2 \geq 0$; a measured $l_1 < 0$ would falsify the framework
- the magnitude of l_1 is a material coefficient: a null result cannot falsify



Log–log plot. C1: the l_1 channel; C2: constant loss angle; C3: I-independent torque coefficient (l_2).

Experiment II: the PNM torsion pendulum

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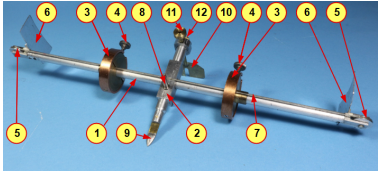
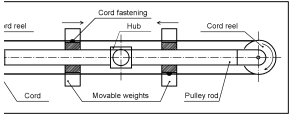




The cord mechanism keeps the two masses at the same r.

- design principle of Maxwell's torsional apparatus; designer and constructor: T. Pálinkás
- two movable masses, $31.7\,\mathrm{g}$ each, at $r = 9.4\,\mathrm{mm}$ to $91.1\,\mathrm{mm}$
- moment of inertia varied by a factor of 6 at fixed suspension and torsion constant; frequency by 2.45
- fibre: Pt–10Ir, $70\,\mu\mathrm{m}$, $200\,\mathrm{mm}$
- total $Q = 14.9$ to 30.2
- optical readout $\pm 2.5°$, sampled at $8\,\mathrm{Hz}$; period channel on a $10\,\mathrm{MHz}$ TCXO
- vessel can be pumped to about $6\,\mathrm{kPa}$ (absolute)

Experiment III: commissioning data and two-step analysis

manuscript tested

Data: twelve free decays at six arm settings, in air at atmospheric pressure.

Step 1: each setting gives (β, ω_0^2), without geometric input.

Step 2a, period line (scale; $I = 2(I_0 + mr^2)$):

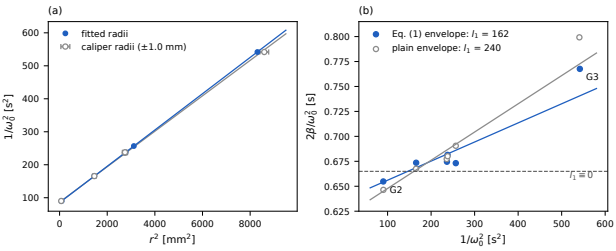
$$\frac{1}{\omega_0^2} = \frac{2I_0}{D} + \frac{2m}{D}\, r^2$$

$D = 1.180(20) \times 10^{-6}$ N m,
$I_0 = 5.11(11) \times 10^{-5}$ kg m^2 (caliper distances): scale known to $1.7\,\%$.

Step 2b, damping line:

$$2\beta = l_1 D + \frac{l_2}{D}\, \omega_0^2$$

The C1 amplitude $l_1 D$ is the intercept; no geometric quantity enters.



(a) Period line. (b) Damping line drawn as $2\beta/\omega_0^2$ against $1/\omega_0^2$, where $l_1 D$ is the slope; filled: extended, open: plain envelope model; dashed: best fit with $l_1 \equiv 0$. In the legend 'Eq. (1) envelope' means the extended envelope model.

Experiment IV: result, degeneracies, next steps

manuscript tested open

Damping line: l_1 in $\mathrm{s\,kg^{-1}\,m^{-2}}$

envelope	settings	l_1	jackknife*
extended	G1–G6	162 ± 30	± 40
extended	without G3	126 ± 28	± 85
extended	without G2, G3	26 ± 45	± 168
plain	G1–G6	240 ± 25	± 48
plain	without G3	204 ± 16	± 29
plain	without G2, G3	172 ± 45	± 263

* jackknife: change of l_1 when one arm setting is left out of the fit

No detection is claimed. The amplitude changes by ≈ 80 with the envelope model and rests on the two extreme settings.

Plain envelope model: damped oscillator + linear drift +constant offset. Extended: +second mode (3 parameters)

The one supported statement ($l_2 \geq 0$, largest inertia): $l_1 < 1.3 \times 10^3\ \mathrm{s\,kg^{-1}\,m^{-2}}$

Degeneracies of the C1 channel

- **gas drag** on the moving masses: apparent $l_1 D = k/m$, of the size of the fitted value
- **anelastic relaxation** of the fibre: $2\beta = D\Delta\tau_r/(I + D\tau_r^2)$; not removed by pumping, not bounded by the data
- the arm scan tests whether l_1 is *independent of* I, not whether it exists

Next measurements

- pressure dependence at fixed arm setting
- second fibre, different D: $l_1 D \propto D$, gas drag not
- frame inertia to $1\,\%$ with arm distances to $0.2\,\mathrm{mm}$, or a creep test

Newtonian gravity from thermodynamics

published derived open

Internal variable = gravitational potential ϕ, with the extra energy density (Ohanian form)

$$\varepsilon_{\mathrm{NG}} = \varrho\phi + \frac{1}{8\pi G}\nabla\phi\cdot\nabla\phi.$$

Zero dissipation and classical holography give the coupled equations

$$\dot{\mathbf{v}} = -\nabla(\mu_{\mathrm{fl}} + \phi), \qquad \Delta\phi = 4\pi G\varrho.$$

The field equation is not postulated; ϕ is a mechanical potential because of the holographic property.

Why this energy density? Maxwell's $-(\nabla\phi)^2/8\pi G$ and Bondi's $\varrho\phi/2$ give the same total energy, but only the Ohanian form generates the Poisson equation: the second law acts as gauge fixing among equivalent balances.

Admissible modifications

- **density–gravity coupling** $b_{12} = C/\varrho$:

$$\Delta\phi = 4\pi G\left(\varrho - C\,\nabla\cdot\frac{\nabla\varrho}{\varrho}\right)$$

- **self-interacting gravity**: the structure of the quantum potential (see quantum fluids):

$$\frac{\Delta\sqrt{\phi}}{\sqrt{\phi}} = \frac{2\pi G}{c^2}\,\varrho$$

Observations. Nonlinear extension $\Delta\phi = 4\pi G\varrho + K\,\nabla\phi\cdot\nabla\phi$: galactic rotation curves, next slide published. Density–gravity coupling: testable with seismic data (Kozak–Wojnar 2022) open.

Quantum fluids I: from fluid to wave function

published derived

Holographic fluid

$$\dot{\varrho} + \varrho \nabla \cdot \mathbf{v} = 0, \qquad \dot{\mathbf{v}} + \nabla \Phi = 0$$

Vorticity $\boldsymbol{\omega} = \nabla \times \mathbf{v}$ is frozen in:

$$\varrho \left(\frac{\boldsymbol{\omega}}{\varrho} \right)^{\triangledown} = 0$$

($^{\triangledown}$: upper-convected derivative). For sufficiently smooth solutions

$$\boldsymbol{\omega}(0) = \mathbf{0} \;\Rightarrow\; \boldsymbol{\omega}(t) = \mathbf{0}, \qquad \mathbf{v} = \nabla S.$$

Bernoulli equation: $\partial_t S + \frac{1}{2} \nabla S \cdot \nabla S + \Phi = \text{const.}$

One complex field ($\varrho > 0$, S_0 arbitrary constant)

$$\Psi = \sqrt{\varrho}\, e^{\mathrm{i}S/S_0}$$

Continuity + Bernoulli are equivalent to

$$\mathrm{i}S_0 \frac{\partial \Psi}{\partial t} = \left(-\frac{S_0^2}{2} \Delta + \Phi + \frac{S_0^2}{2} \frac{\Delta |\Psi|}{|\Psi|} \right) \Psi.$$

A wave-function representation exists for *any* holographic potential Φ; in general the equation is nonlinear.

Szücs–Ván, Phys. Fluids 38, 118116 (2026), Sec. III.D–E, Eqs. (86), (103)–(107)

Quantum fluids II: linearity selects the Schrödinger equation

published derived

Requirement of linearity fixes the potential:

$$\Phi_{\text{free}} = -\frac{S_0^2}{2}\frac{\Delta|\Psi|}{|\Psi|} \;\Rightarrow\; \mathrm{i}S_0\frac{\partial\Psi}{\partial t} = -\frac{S_0^2}{2}\Delta\Psi.$$

With $S_0 = \hbar/m$ and an external potential V:

$$\mathrm{i}\hbar\frac{\partial\Psi}{\partial t} = \Big(-\frac{\hbar^2}{2m}\Delta + V\Big)\Psi.$$

The Bohm potential corresponds to the Fisher form of the extra energy:

$$\frac{\varepsilon_K}{\varrho} = \frac{\hbar^2}{8m^2}\frac{\nabla\varrho\cdot\nabla\varrho}{\varrho^2}.$$

Derived

The Schrödinger equation: the basic equation of single-particle quantum dynamics, embedded in thermodynamically compatible fluid theory.

Input, not derived

The value of $\hbar$; single-valuedness of the phase (quantized circulation); the probabilistic reading $\varrho = m|\Psi|^2$; the operator structure is conditional.

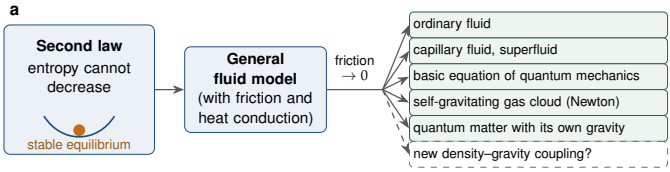
No canonical structure is assumed: a thermodynamic quantization, in principle applicable to purely dissipative systems (heat conduction: next step).

Instead of linearity: additivity. For independent subsystems the requirement $u(\varrho_1\varrho_2) = u(\varrho_1) + u(\varrho_2)$ on the specific energy has the unique solution $u = k\ln\varrho + \kappa(\nabla\varrho)^2/2\varrho^2$: the Fisher form.

Szücs–Ván, Phys. Fluids 38, 118116 (2026), Eqs. (108)–(112), (145)

Quantum fluids III: one family, with gravity

published derived open



Quadratic extra energy

$$\varepsilon = a_1\varphi + \frac{a_2}{2}\varphi^2 + \frac{1}{2}\begin{pmatrix}\nabla\varrho & \nabla\varphi\end{pmatrix}\begin{pmatrix}b_1 & b_{12}\\ b_{12} & b_2\end{pmatrix}\begin{pmatrix}\nabla\varrho\\ \nabla\varphi\end{pmatrix}$$

Newtonian gravity ($\varphi \equiv \phi$): $a_1 = \varrho$, $b_2 = \dfrac{1}{4\pi G}$

Schrödinger–Madelung: $b_1 = \dfrac{\hbar^2}{4m^2\varrho}$, $\mu_{\mathrm{fl}} = 0$

Quantum fluid with its own gravity ($b_{12} = C/\varrho$)

$$\mathrm{i}\hbar\frac{\partial\Psi}{\partial t} = \left(-\frac{\hbar^2}{2m}\Delta + V + m\phi + m\mu_{\mathrm{fl}} - \frac{C}{|\Psi|^2}\Delta\phi\right)\Psi$$

$$\Delta\phi = 4\pi G m\left(|\Psi|^2 - \frac{C}{m}\Delta\ln|\Psi|^2\right)$$

$C = 0$: Schrödinger–Newton. $C \neq 0$: admissible only for $\varrho \geq \varrho_c = 16\pi G m^2 C^2/\hbar^2$; existence in nature is open.

Szücs–Ván, Phys. Fluids 38, 118116 (2026), Eqs. (113), (158), (164)–(165)

Where we stand: compatibility, tests, open points

prediction	compatible with	tested	open
classical holography	Euler, Korteweg, Schrödinger–Madelung fluids, Newtonian gravity, Schrödinger–Newton: one family	condition $\nabla s \times \nabla T = \mathbf{0}$ derived derived; galactic rotation curves described by modified gravity published	no new vorticity sources; density–gravity coupling; $\varrho \to 0$ and quantized vortices
fundamental dynamic stability	Fourier–Navier–Stokes; Fourier, MCV, Guyer–Krumhansl, Extended Thermodynamics	theorem for third-order heat conduction derived; Guyer–Krumhansl heat conduction at room temperature tested	nonlinear stability; relativistic dissipative fluids
dissipative momentum	Newton equation, damped oscillator, Eliezer–Ford–O'Connell equation as limits	PNM torsion pendulum: $l_1 < 1.3 \times 10^3\,\mathrm{s\,kg^{-1}\,m^{-2}}$, no detection tested	separation from gas drag and anelasticity; test with a second fibre; continuum theory

Logic of the experimental test. The framework predicts the form of the equations and the sign of the coefficients, not the magnitude of l_1: a null result cannot falsify it, a measured $l_1 < 0$ would.

Back to irreversibility: what about quantum mechanics?

manuscript plan open

The objection. The Schrödinger equation is ideal and, in the usual sense, time-reversal invariant. If quantum mechanics is fundamental, where is the room for microscopic irreversibility?

Two answers from this talk

- **covariant time reversal:** only the free equations are invariant (Maxwell, Newton); whether this holds for the Schrödinger equation with a potential is to be checked open
- **thermodynamic route:** the Schrödinger equation is the zero-dissipation limit of a fluid theory that is dissipative by construction; the viscous, thermal and internal-variable terms are there before the limit derived

Open

- which dissipative quantum fluid? Comparison with the Lindblad-type master equations of the damped oscillator (Dekker, Diósi): Caldeira–Leggett + dissipative momentum = Lindblad dynamics
- probability: an input in the fluid derivation; could come from the unknown particle–field interaction?
- classical–quantum transition and measurement with dissipation: planned numerical modelling plan

If irreversibility is built in, the ideal quantum equation is a limit, not the foundation.

T. Matolcsi, manuscript (2026); Szücs–Ván, Phys. Fluids 38, 118116 (2026); Dekker, Phys. Rep. 80, 1 (1981); Diósi, EPL 22, 1 (1993)

Open questions and perspectives

plan open

Within reach of the method

- **Experiment:** pressure dependence, a second fibre with different D, a creep test
- **Dissipative momentum in continua:** higher-order weakly nonlocal theory; rheology, radiation reaction
- **Quantized heat conduction:** the comparison with experiments is the task
- **Heat conduction:** three-dimensional and pure internal-variable versions of the stability theorem
- **Density–gravity coupling:** tests with seismic data (COST Action FuSe)
- **Covariant formulations:** MFI concepts, Newton–Cartan vs. flat space-times
- **Plasma physics:** numerical simulation of predicted effects

Open: new ideas are needed

- nonlinear and dissipative stability of the complete matter–field system: the touchstone of the strategy
- hyperbolic extension, Godunov–Friedrichs–Lax–Boillat theorem for weakly nonlocal continua
- relativistic dissipative fluids: stability does not yet follow from thermodynamics; the extension of the Liu procedure is not evident
- $\varrho \to 0$ and quantized vortices; other concepts of quantum theory in the fluid framework
- microscopic origin of l_1; Galilean covariant dissipative mechanics
- microdissipation limits: calculation and evaluation
- an equation for the particle–field interaction
- ...

Perspective: how far can we get with the concepts and methods of thermodynamics?

Dissipative physics?

Concepts

- the usual time reversal is not covariant; only the free equations (and interaction!) are time-reversal invariant
- the laws of thermodynamics are stability requirements
- used constructively, they restrict the ideal equations as well: classical holography, functional derivatives without variational principles

Consequences so far

- **Newton's dynamical law:** dissipative momentum, $2\beta = l_1 D + l_2/I$; torsion pendulum: $l_1 < 1.3 \times 10^3\,\mathrm{s\,kg^{-1}\,m^{-2}}$, no detection yet
- **Newtonian gravity:** the field equation from the second law; admissible modifications, galactic rotation curves
- **Quantum fluids:** the Schrödinger equation from linearity; one family with gravity

Ideal Newtonian mechanics, Newtonian gravity and the Schrödinger equation appear as zero-dissipation limits of a dissipative theory.

The second law is both fundamental and emergent: the same general law can arise from many microscopic realizations.

Supported by NKFIH, grant NKKP Advanced 150038.

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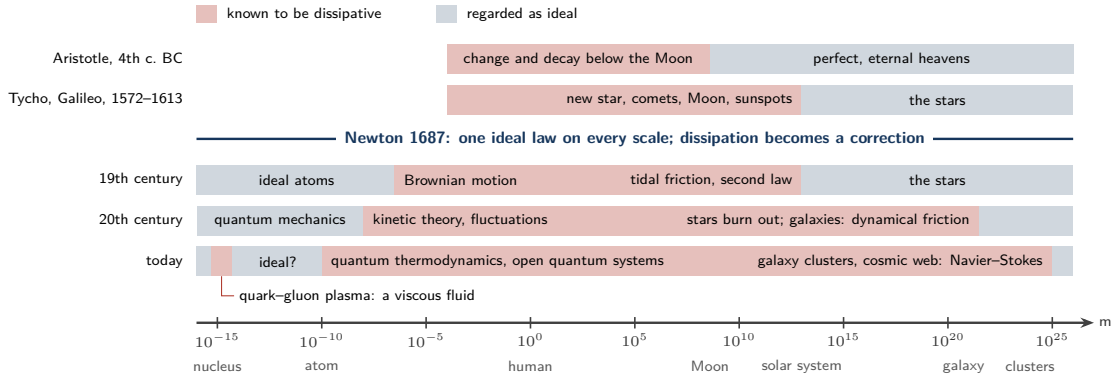
Backup: the retreat of the perfect world



Layer after layer turned out to be imperfect. The ideal world survives only towards the small scales, and less and less there.

Yet the laws regarded as fundamental are still the ideal ones.

Schematic compiled for this talk; landmarks: Tycho (1572, 1577), Galileo (1610, 1613), Newton (1687), Chandrasekhar (1943), Lindblad (1976)

Backup: Experiment evaluation demo

Equation of motion:

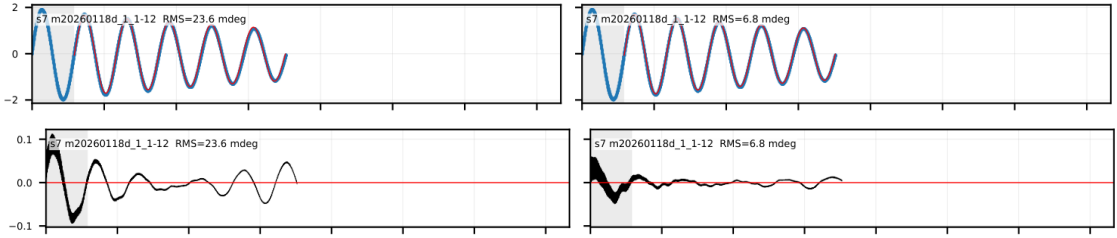
$$\Theta\ddot{\alpha} - (l_2 + \boxed{l_1\Theta D})\dot{\alpha} + \hat{D}\alpha = 0$$

α - torsion angle, $\Theta = \Theta_0 + 2mL^2$ - moment of inertia

Damping coefficient:

$$b(L) = \frac{l_2 + l_1\Theta D}{\Theta} = \boxed{l_1 D} + \frac{l_2}{\Theta_0 + 2mL^2}$$

Modell A: $l_1 = 0$. Model B: $l_1 \neq 0$



Backup: time reversal and the Newton equation

Frames and time reversals ($c = 1$, one space dimension)

$$
\begin{aligned}
T:&\ (t,x) \mapsto (-t,x)\\
L_v:&\ (t,x) \mapsto \gamma\,(t - vx,\ x - vt)\\
&L_v T\,(t,x) = \gamma\,(-t - vx,\ x + vt)\\
&T' L_v\,(t,x) = \gamma\,(-t + vx,\ x - vt)
\end{aligned}
$$

Hence $L_v T = T' L_{-v} \neq T' L_v$: the time reversal of one frame is not the time reversal of the other.

Space-time form: for a space-time point o and a four-velocity u

$$T_{(u,o)}(x) = x + 2\Big(u\cdot(x-o)\Big)u, \qquad T_u x = x + 2(u\cdot x)\,u.$$

Continuum: $m\rho\, D_U U = F \cdot e\rho U$ is time-reversal invariant if and only if $F \cdot e\rho U = 0$.

Point particle, world line $s \mapsto r(s)$, proper time s.

The (u,o)-reversed world line is $s \mapsto T_{(u,o)}\, r(\sigma)$ with $\sigma := s_o - (s - s_o)$, where $\Big(r(s_o) - o\Big)\cdot u = 0$. Then

$$\frac{\mathrm{d}}{\mathrm{d}s}\, T_{(u,o)} r(\sigma) = -T_u \dot r(\sigma), \qquad \frac{\mathrm{d}^2}{\mathrm{d}s^2}\, T_{(u,o)} r(\sigma) = T_u \ddot r(\sigma).$$

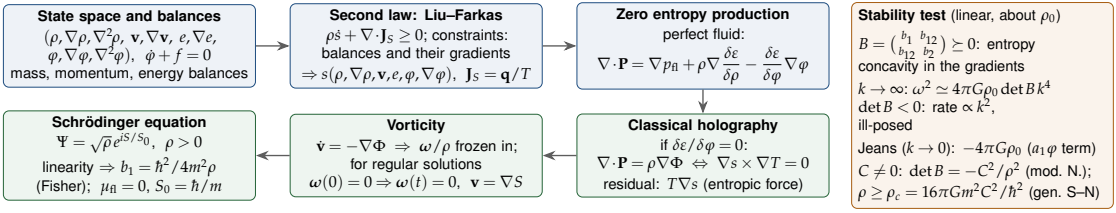
The Newton equation $m\ddot r = f(r, \dot r)$ is time-reversal invariant if, for all o, u and s,

$$
\begin{aligned}
m\, T_u \ddot r(\sigma) &= T_u \Big(f\Big(T_{(u,o)} r(\sigma),\ -T_u \dot r(\sigma)\Big)\Big)\\
&= f\Big(r(s), \dot r(s)\Big) = m\,\ddot r(s).
\end{aligned}
$$

At $s = s_o$: $T_u \ddot r(s_o) = \ddot r(s_o)$ for all o and u, which holds if and only if $\ddot r = 0$, that is $f = 0$.

($T_u a = a$ means $u \cdot a = 0$; for all four-velocities u this gives $a = 0$.)

Backup: logical structure of Szücs–Ván (2026)



Blue: construction from the second law; green: consequences of the zero-dissipation limit; orange: stability conditions from the linearization of the dissipation-free generalized Schrödinger–Newton system.