CURRICULUM VITAE – ARTO ANNILA

1. PERSONAL DETAILS

Annila, Arto Jaakko
ORCID: 0000-0003-2955-2389
Google Scholar page, Homepage
Date and place of birth: 5 November 1962, Helsinki, Finnish citizenship
Home address: Kirvuntie 27, FI-02140 Espoo, Finland
Email: arto.annila@helsinki.fi Mobile: +358 44 204 7324
Date: 26 February 2025

2. DEGREES

Ph.D. (Doctor of Technology), Aalto University (Helsinki University of Technology), Technical Physics, 20.8.1991,
Docent in Physical Chemistry, University of Helsinki, 28.4.1999
M.Sc. in Biochemistry, University of Helsinki, 26.4.1996
Qualified teacher in mathematics and physics, University of Helsinki, 08.06.2017 (60 ETCS)

3. LANGUAGE SKILLS

Native in Finnish
English: Fluent since exchange student in the USA; Swedish: Fluent after military service in Swedish-speaking garrison; German: Laudatur in student examination; Danish: at best tolerable after two years at Risø; French: one year course at Aalto University.

4. CURRENT EMPLOYMENT

Senior Scientist at a startup, Nanoform Finland Ltd, since 01.07.2017.

5. PREVIOUS WORK EXPERIENCE

Professor of Biophysics from 2001 to 2016 at the University of Helsinki.
In 2016, when the University of Helsinki was subject to cuts, I was dismissed, as were nine other professors. The real reason for my groundless dismissal was that the then-head of the Department of Physics could not accept my research results deriving from thermodynamics but, thereby, contrasting certain contemporary indoctrinations. Please get acquainted with my publications and the book *Back to Reality: A Revision of the Scientific Worldview*, also available as pdf. The book explains to the lay audience how nature works.

Timeline from the present to the past.

2017	Looking for new opportunities as Senior Scientist at Nanoform Finland Ltd since dismissal from the University of Helsinki 2016
2008	Professor of Biophysics, University of Helsinki (tenured)
2001	Professor of Biophysics, University of Helsinki (tenure)
2001	Senior Researcher, Academy of Finland
2000	Group Leader, VTT Biotechnology, the State Technical Research Centre of Finland
1998	Group Leader, Structural Biology and Biophysics Program at Viikki Biocenter
1996	Group Leader, Senior Scientist, VTT Chemical Technology, State Technical Research Centre of Finland
1993	Researcher, Academy of Finland
1992	Senior Scientist, VTT Chemical Technology, State Technical Research Centre of Finland
1991	Visiting Scientist at the University of Lund, Department of Physical Chemistry 2
1990	Research Assistant at Low Temperature Laboratory, Helsinki University of Technology
1989	Research Fellow, Danish Research Academy at National Laboratory at Risø, Denmark
1988	Research Assistant, Academy of Finland at Low Temperature Lab., Helsinki University of Technology
1987	Researcher, Low Temperature Laboratory, Helsinki University of Technology
1986	Research Assistant, Low Temperature Laboratory, Helsinki University of Technology

6. RESEARCH FUNDING

Since 1 July 2017, I have been in charge of getting funding from public sources for a startup company, Nanoform Finland Ltd, which was granted 1 M€ for the development of nanoparticle formulation.

Previously obtained funding
(full years for the salary of one researcher, Ph.D.)
1994-1995 Academy of Finland, Cardiac Troponin C Molecular Structure and Function
1993-1996 Academy of Finland, Cellulase-Cellulose Interaction
1995-1997 Academy of Finland, Cyanobacterial Toxins and Protein Phosphatase Interaction
1995 Orion-Farmos International, Conformation of a Segment from a Membrane Receptor
1996 Orion-Farmos International, Structure of a Membrane-Bound Oligomer
1998-2000 Academy of Finland, Cardiac Troponin C Structure and Function
1997-1999 TEKES and Orion Pharmaceuticals, Structure Determination of Proteins and Peptides in Drug Discovery
1999-2000 TEKES and Orion Pharmaceuticals, Structure Determination of Proteins and Peptides in Drug Discovery
1999-2001 Academy of Finland, Structure Determination of Protein Folds by Anisotropy Based NMR Methods
1999-2000 TEKES NMR Studies of Metabolic Routes of Genetically Modified Yeast
2000-2002 Academy of Finland, Structural Biology Program
2001-2004 TEKES Development of NMR Methods for Drug Discovery (Drug 2000 Program)
2004-2006 TEKES Development of NMR Methods for Drug Discovery (Drug 2000 Program)
2003-2006 Research grant, protein folding in a confined medium. Academy of Finland
2004-2007 Determination of weakly structured protein conformations. The three-year grant, University of Helsinki
2006-2007 TEKES Development of NMR Methods for Drug Discovery (Drug 2000 Program)

My cross-disciplinary expertise and comprehensive experience allow me to compete for funding, particularly via collaborations beyond the traditional scope of physics. Moreover, my experience complies with the general understanding that it takes time for the scientific community to realize the merits of pioneering work and reward it. On the other hand, when receiving recognition, groundbreaking research will acquire funding from many sources.

7. RESEARCH OUTPUT

The following ten of some 130 publications give an idea of my capacity and scope.

1. Tuisku P, Pernu TK, Annila A. In the light of time. *Proc. R. Soc. A*. 2009 465, 1173–1198.
   A flow of time relates to a quantized flow of energy from a system to its surroundings and vice versa.
2. Sharma V, Kaila VRI, Annila A. Protein folding as an evolutionary process. *Physica A* 2009 388, 851–862.
   Protein folding is shown to be an inherently intractable process as any other evolutionary course.
3. Karnani M, Pääkkönen K, Annila A. The physical character of information. *Proc. R. Soc. A*. 2009 465, 2155.
   Information is physical and communication is a dissipative process among other natural processes given by the 2nd law.
4. Mäkelä T, Annila A. Natural patterns of energy dispersal. *Phys. Life Rev.* 2010 7, 477–498.
   Many mathematical models of systems are found as approximations of the evolutionary equation of motion.
5. Annila A. Least-time paths of light. *Mon. Not. R. Astron. Soc.* 2011 416, 2944–2948.
   The principle of least action gives paths of light through space without dark energy and dark matter.
6. Annila A. The meaning of mass. *Int. J. Theor. Math. Phys*. 2012 2, 67–78.
   Particles are actions whose quantized geodesics manifest as charges, magnetic moments, and masses.
7. Annila A, Wikström M. Dark matter and dark energy denote the gravitation of the expanding universe. *Front. Phys.* 2022
   The gravitational field from the distant dense past to the sparse present accounts for the galaxy rotation, velocity dispersion as well as recession.
8. Lehmonen L, Annila A. Baryon breakdown in black hole. *Front. Phys.* 2022.
   A black hole is described as a star annihilating neutrons into photons that jet out as high-energy density rays.
9. Annila A. Chiral conformity emerges from the least-time free energy consumption. *Interface Focus* 2023 13.
   The flows of energy naturally select standard structures over less-fit functional forms to consume free energy in the least time.
10. Annila A, Wikström M. Quantum entanglement and classical correlation have the same form. *Eur. Phys. J. Plus* 2024 139, 560.
    Classical correlation explaining quantum entanglement clarifies the foundations of modern physics and quantum computing.

In addition, the book *Back to Reality: A Revision of the Scientific Worldview* (Privus Press, 2020), a translation of the original print published in Finnish: *Kaiken maailman kvantit, luonnontieteen maailmankuvan tarkistus* (Vastapaino, 2019) communicates a comprehensive worldview based on the statistical physics of open quantized systems.

8. RESEARCH SUPERVISION AND LEADERSHIP EXPERIENCE

I have supervised the following Ph.D. students: Kimmo Pääkkönen (2003), Maija-Liisa Mattinen (1998), Kai Fredriksson (2007), Martti Louhivuori (2007), Perttu Permi (2000), Helena Aitio (2003, co-tutoring), Tia Sorsa (2003, co-tutoring), Maarit Hellman (2007, co-tutoring) and about dozen M.Sc. students. I have examined B.Sc. 2 – 5 theses per year.

9. TEACHING MERITS

I have taught as a university professor for 15 years and have docent (lecturer/associate professor) status for 25 years. Therefore, I am experienced in lecturing courses in physics at the BSc and MSc levels. Pedagogical training and competence: Pedagogical studies for subject teachers (mathematics and physics) completed 2016 – 2017, 60 ETCS.

I was in charge of Biophysics and Medical Physics curriculum planning and implementation of courses (Finnish: Opetusresurssityöryhmän jäsen 2015).

I led the researcher training group (Finnish: Tutkijalinja) at the Department of Physics, the University of Helsinki, until 2016.

I taught at the Faculty of Biosciences and the Faculty of Science, 6 – 8 interdisciplinary courses per year. For further activities, please see https://tuhat.helsinki.fi/portal/en/ for Arto Annila.

Biophysics 1 (5 ETCS) 2002-2015
Biophysics 2 (5 ETCS) 2002-2015
Origin of biodiversity (3 ETCS) 2009-2016
Molecular biophysics for bioscientists (3 ETCS) 2002-2015
Statistics for bioscientists (3 ETCS) 2008-2015
Biomolecular NMR spectroscopy (5 ETCS) 2002-2015 (every second year)
Protein folding (5 ETCS) 2002-2012 (every second year)
Pro gradu seminar (3 ETCS) 2008-2016
Wave mechanics (5 ETCS) 2002-2008

As a teacher, I generate and recruit motive forces to power motion toward a consistent and comprehensive worldview. Conversely, inconsistencies in rationales and exceptions to rules comprise students' ability to solve problems and track down causes and effects. I engage students in exploring, experimenting, visualizing, simulating, building, tearing apart, and explaining in their own words rather than wearing them out by mere lecturing.

10. AWARDS AND HONOURS

Science Aphorism Award 2016.
Entropy Journals award for the paper "Economies evolve by energy dispersal" with Stanley Salthe, 2010.

11. OTHER ACADEMIC MERITS

Opponent of a doctoral dissertation of TongLing Lin, a student of Prof. Q. Alexander Wang, Le Mans 2011.
Pre-examiner of Harri Koskela's thesis, a student of Prof. Ilkka Kilpeläinen, Helsinki.

Reviewer for *Biochemistry, EMBO J., FEBS Letters, J. Am. Chem. Soc., J. Biomol. NMR, J. Mol. Biol., Protein Sci., Entropy, Math.Biosci., App. Math. Model., J. Non-Eq. Thermod., Int. J. Mol. Sci., Ecol. Mod., Int. J. Astrobio., Information, Physica A, Systems, Complexity, Chem. Phys. Letters, J. Phys. Chem., Theor. Biosci., Europhys. Letters, J. Roc. Soc. Interface., Front. Systems Neurosci.*

Graduate school supervisor & membership in ISB and MATERNA. Memberships in the advisory boards of Finnish Technology Agency projects, the Nordic NMR Meeting 2001 organizing committee. Member of Societas Biochemica, Biophysica & Microbiologica Fenniae, The Finnish Society for Natural Philosophy, and The Finnish Physical Society. Board member of the University of Helsinki Science Library, Publication Center of The Federation of Finnish Learned Societies (TSV). Chairman of the researcher training program at the Department of Physics.

12. SCIENTIFIC AND SOCIETAL IMPACT

CITED BY (see Homepage, Quoted)
Phys.Org. https://phys.org/search/?search=annila
Evolution as Described by the Second Law of Thermodynamics, 2008 Why Life Originated (And Why it Continues), 2008. Second Law of Thermodynamics May Explain Economic Evolution, 2009

A second look at supernovae light: Universe's expansion may be understood without dark energy, 2011. A challenge to the genetic interpretation of biology, 2014.
Science Alert: *New paper claims that the EM Drive doesn't defy Newton's 2nd law, 2016.*
Finding Genius Podcast: *Everything is light, 20 January 2020.*

TALKS

Thermodynamic foundations of evolutionary theory. Joint Eur. Therm. Conf., Jun. (2009) Copenhagen, Denmark (invited)
Worldview guided by the least action. Conf. of the Finnish Society for Natural Philosophy, Sept. (2010) Helsinki, Finland
Natural emergence. Finnish Physics Days, March 29-31 (2011) Helsinki, Finland
Ajatuksia ajattelusta yleisen luonnonlain mukaan. Conf. Finnish Society for Natural Philosophy, Sept. (2011) Helsinki
The meaning of mass. Finnish Physics Days, March 13-15 (2012) Joensuu, Finland
The Character of Natural Law, 2 February (2013) ISMANS, Le Mans & 21 February (2013) ENS, Paris
The energetic principle of nature. Systems ecological perspectives on sustainability 25 September (2014), Helsinki Selittävätkö luonnonlait kaiken? Jan. 14 (2015) Jyväskylän ikääntyvien yliopisto, Jyväskylä
The Natural Law. Sept. 9 (2015) sDiV, Leipzig
Universal paradigm. 23 Mar. (2016) Helsinki
Efficiency in Complex Systems: Satellite Session at Conference on Complex Systems, (2017), Cancun
Revival of Realism, Physics beneath Modeling: Physics Beyond Relativity, October 18-21 (2019), Prague
Kaiken maailman kvantit: Society for Natural Philosophy, September 29 (2020), Helsinki
Thermodynamics of universal patterns: International Conference on Thermodynamics 2.0 Jul. 18-20, (2022) Boone, North Carolina

13. OTHER MERITS

Finnish military rank: Captain

LIST OF PUBLICATIONS – ARTO ANNILA

1.1. THE MOST RELEVANT PEER-REVIEWED PAPERS

(FULL TEXT AVAILABLE FROM: HTTPS://WWW.MV.HELSINKI.FI/HOME/AANNILA/ARTO/PAPERS.HTML, HTTPS://WWW.RESEARCHGATE.NET/, HTTPS://SCHOLAR.GOOGLE.FI/) Need more information, email arto.annila@helsinki.fi or phone +358 44 204 7324.

1. Sharma V, Annila A. Natural process – Natural selection. *Biophys. Chem.* 2007 127, 123–128.
   Evolution is formulated as a systemic equation of motion by the principle of increasing entropy.
2. Grönholm T, Annila A. Natural distribution. *Math. Biosci.* 2007 210, 659–667.
   Ubiquitous power laws and lognormal distributions are found to follow from the 2nd law of thermodynamics.
3. Kaila VRI, Annila A. Natural selection for least action. *Proc. R. Soc. A*. 2008 464, 3055–3070.
   The principle of least action is shown as equivalent to the 2nd law of thermodynamics and Newton's 2nd law.
4. Jaakkola S, Sharma V, Annila A. Cause of chirality consensus. *Curr. Chem. Biol.* 2008 2, 53–58. arXiv:0906.0254
   Standards of natural and artificial systems are found to follow the 2nd law of thermodynamics.
5. Würtz P, Annila A. Roots of diversity relations. *J. Biophys.* 2008, 654672, arXiv:0906.0251
   Species-area and other systemic relationships are found to follow from the 2nd law of thermodynamics.
6. Annila A, Annila E. Why did life emerge? *Int. J. Astrobio.* 2008 7, 293–300.
   Life in its entirety is a natural process resulting from the least-time free energy consumption.
7. Tuisku P, Pernu TK, Annila A. In the light of time. *Proc. R. Soc. A*. 2009 465, 1173–1198.
   A flow of time relates to a quantized flow of energy from a system to its surroundings and vice versa.
8. Karnani M, Annila A. Gaia again. *BioSystems* 2009 95, 82–87.
   Global homeostasis is a maximum entropy state equivalent to a free energy minimum state.
9. Sharma V, Kaila VRI, Annila A. Protein folding as an evolutionary process. *Physica A* 2009 388, 851–862.
   Protein folding is shown to be an inherently intractable process as any other evolutionary course.
10. Annila A, Kuismanen E. Natural hierarchy emerges from energy dispersal. *BioSystems* 2009 95, 227–233.
    The rise of the hierarchy is a consequence of the least-time free energy consumption.
11. Karnani M, Pääkkönen K, Annila A. The physical character of information. *Proc. R. Soc.A*. 2009 465, 2155–2175.
    Information is physical due to its representations that are subject to the 2nd law of thermodynamics.
12. Annila A, Salthe S. Economies evolve by energy dispersal. *Entropy* 2009 11, 606–633.
    Economies are energy transduction systems that follow the 2nd law of thermodynamics.
13. Würtz P, Annila A. Ecological succession as an energy dispersal process. *BioSystems* 2010 100, 70–78.
    Succession of a system from one state to another is a manifestation of the 2nd law of thermodynamics.
14. Annila A. The 2nd law of thermodynamics delineates dispersal of energy. *Int. Rev. Phys.* 2010 4, 29–34.

The universal law for open evolving systems is given in its diverse forms.

15. Annila A. All in action. *Entropy* 2010 12, 2333–2358. arxiv.org/abs/1005.3854
Nature, in its entirety, is described in terms of quantized actions and related mathematical conjectures are examined.
16. Annila A, Salthe S. Cultural naturalism. *Entropy* 2010 12, 1325–1343. doi:10.3390/e12061325
Culture is described as a society's means to consume free energy.
17. Annila A, Salthe S. Physical foundations of evolutionary theory. *J. Non-equilb. Therm.* 2010 35, 301–321.
The theory of evolution by natural selection is subsumed by the 2nd law of thermodynamics.
18. Mäkelä T, Annila A. Natural patterns of energy dispersal. *Phys. Life Rev.* 2010 7, 477–498.
Many mathematical models of systems are found as approximations of the evolutionary equation of motion.
19. Annila A. Least-time paths of light. *Mon. Not. R. Astron. Soc.* 2011 416, 2944–2948.
The principle of least action gives paths of light through space without dark energy and dark matter.
20. Koskela M, Annila A. Least-action perihelion precession. *Mon. Not. R. Astron. Soc.* 2011 417, 1742–1746.
Perihelion precession is calculated using the principle of least action and ascribed to the gravity of the universe.
21. Anttila J, Annila A. Natural games. *Phys. Lett. A* 2011 375, 3755–3761. arxiv.org/abs/1103.1656
Behavior in the context of game theory is described as a natural process.
22. Hartonen T, Annila A. Natural networks as thermodynamic systems. *Complexity* 2012 18, 53–62.
Universal characteristics of networks follow from the least-time free energy consumption.
23. Annila A, Kallio-Tamminen T. Tangled in entanglement. *Physics Essays* 2012 25, 495–499.
Conceptual conundrums of quantum mechanics are resolved using the principle of least action.
24. Annila A. Probing Mach's principle. *Mon. Not. R. Astron. Soc.* 2012 423, 1973–1977.
The principle of least action accounts for geodetic precession and frame-dragging effects.
25. Annila A. Space, time and machines. *Int. J. Theor. Math. Phys*. 2012 2, 16–32. arxiv:0910.2629
Key problems in physics and conjectures of mathematics are addressed by the universal law of least action.
26. Annila A. The meaning of mass. *Int. J. Theor. Math. Phys*. 2012 2, 67–78. sapub.org/10.5923
Particles are actions whose quantized geodesics manifest as charges, magnetic moments, and masses.
27. Pernu TK, Annila A. Natural emergence. *Complexity* 2012 17, 44–47. doi:10.1002/cplx.21388
New qualities materialize when surrounding quanta incorporate into the system opening new motional modes.
28. Koskela M, Annila A. Looking for LUCA. *Genes* 2012 3, 81–87.
The unattainable quest for the last universal common ancestor implies an impaired understanding of what life is.
29. Annila A, Annila E. The significance of sex. *BioSystems* 2012 110, 156–161.
Both sexual and asexual reproduction can be regarded merely as a means of least-time free energy consumption.
30. Keto J, Annila A. The capricious character of nature. *Life* 2012 2, 165–169.
Courses of nature are inherently unpredictable since processes and their driving forces depend on each other.
31. Annila A. Physical portrayal of computational complexity. *ISRN Comp. Math.* 2012 321372, 1–15. arXiv:0906.1084
Computation is intractable when there are degrees of freedom for dissipative computational steps.
32. Annila A, Salthe S. On intractable tracks. *Physics Essays* 2012 25, 232–237.
The principle of least action explains why nature shows rules and regularities but is nevertheless unpredictable.
33. Annila A, Salthe S. Threads of time. *ISRN Therm.* 2012 850957.
The flux of quanta embodies the flow of time; irreversible free energy consumption creates time's arrow.
34. Varpula S, Annila A, Beck C. Thoughts about thinking. *Advanced Studies in Biology* 2013 5, 135–149.
A holistic account of the human brain is given by the systemic theory of least-time free energy consumption.
35. Annila A, Baverstock K. Genes without prominence: a reappraisal of the foundations of biology. *J. Roc. Soc. Interface* 2014 11, 20131017.
Genes are no ends in themselves but at the service of least-time free energy consumption.
36. Annila A, Kolehmainen E. On the divide between animate and inanimate. *J. Sys. Chem.* 2015 6, 2
Ubiquitous patterns present evidence that demarcation between animate and inanimate is only imaginary.
37. Annila A. The substance of gravity. *Physics Essays* 2015 28, 208–218.
A local gravitational potential and the universal vacuum embody energy in photon pairs without net polarization.
38. Annila A. Cosmic rays report from the structure of space. *Advances in Astronomy* 2015 id 135025.
Spectral features of rays relate by the least-time principle to energy densities of the vacuum in the expanding universe.
39. Annila A. Natural thermodynamics. *Physica A* 2016 444, 843–852.
Universal characteristics and principles are derived by considering quantized actions to embody every system.
40. Annila A. On the character of consciousness. *Frontiers in Systems Neuroscience* 2016 10, 27. doi:

10.3389/fnsys.2016.00027

Several well-known questions about consciousness are examined and illuminated by statistical physics.

41. Annila A. Rotation of galaxies within gravity of the universe. *Entropy* 2016 18, 191–205.
The galaxy rotation is explained by the principle of least action to result from the overall gravity of the expanding universe.
42. Grahn P, Annila A, Kolehmainen E. On the exhaust of EM-drive. *AIP Advances* 2016 6, 065205.
The elusive thrust of an electromagnetic drive is identified by the principle of least action to emitted paired photons.
43. Annila A, Baverstock K. Discourse on order vs. disorder. *Communicative & Integrative Biology* 2016 9, e1187348.
Increase in disorder, just as order, in any system is merely a consequence of least-time free energy consumption.
44. Annila A, Kolehmainen E. Atomism revisited. *Physics Essays* 2016 29, 532–541.
Ancient atomism guides to construct everything from indivisible entities, known today as the quantum of actions.
45. Annila A. Flyby anomaly via least action. *Progress in Physics* 2017 13, 92–99.
The unexpected velocity changes during spacecraft flybys of Earth are accounted for by the principle of least action.
46. Annila A. Evolution of the universe by the principle of least action. *Physics Essays* 2017 30, 248–254.
Path-dependent and scale-free characteristics of universal evolution are accounted for by the principle of least action.
47. Koivu-Jolma M, Annila A. Epidemic as a natural process. *Mathematical Biosciences* 2018 299, 97–102.
Path-dependent and scale-free characteristics of universal evolution are accounted for by the principle of least action.
48. Grahn P, Annila A, Kolehmainen E. On the carrier of inertia. *AIP Advances* 2018 8, 035028.
Inertia is described as a reaction taken to action by the paired-photon embodied vacuum.
49. Annila A. The art of abstraction: Comment on "Morphogenesis as Bayesian inference" by Kuchling, et al. *Phys. Life Rev.* 2020 33, 119–120 doi: 10.1016/j.plrev.2019.11.008
The principle of morphogenesis is spelled out.
50. Annila A. The matter of time. *Entropy* 2021 23, 943–956. doi: 10.3390/e23080943
The photon period is the elemental unit of time; time flows as quanta flow.
51. Annila A. Statical physics of evolving systems. *Entropy* 2021 23, 1590. doi: 10.3390/e23121590
Based on the axiom of everything comprising quanta, all systems evolve toward thermodynamic balance with their surroundings.
52. Annila A. The fundamental nature of motives. *Frontiers in Neuroscience* 28.1.2022 doi: 10.3389/fnins.2022.806160
The motive forces orient agents to consume free energy in the least time.
53. Lehmonen L, Annila A. Natural classes and natural classification. *In Efficiency in Complex Systems*, ed. Georgiev GY, Shokrollahi-Far, M. Springer Nature 2022. doi: 10.1007/978-3-030-69288-9
Natural categorization places objects into classes so that free energy is consumed in the least time.
54. Annila A. On the origin of universal patterns. *In Efficiency in Complex Systems*, ed. Georgiev GY, Shokrollahi-Far, M. Springer Nature 2022. doi: 10.1007/978-3-030-69288-9
The ubiquitous patterns follow from the least-time consumption of free energy.
55. Lehmonen L, Annila A. Baryon breakdown in black hole. *Front. Phys.* 2022, doi: 10.3389/fphy.2022.954439
A black hole is described as a star annihilating neutrons into photons that jet out as high-energy density rays.
56. Annila A, Wikström M. Dark matter and dark energy denote the gravitation of the expanding universe. *Front. Phys.* 2022, doi: 10.3389/fphy.2022.995977
The gravitational field from the distant dense past to the sparse present accounts for the galaxy rotation, velocity dispersion as well as recession.
57. Annila A. Chiral conformity emerges from the least-time free energy consumption. *Interface Focus* 2023 13, doi:10.1098/rsfs.2022.0074.
The flows of energy naturally select standard structures over less-fit functional forms to consume free energy in the least time.
58. Annila A. Philosophy of thermodynamics. *Philosophical Transactions of the Royal Society A*, 2023 7, 381(2252): 20220281 doi:10.1098/rsta.2022.0281
The holistic worldview provides a perspective on questions such as what the world is, how we know about it, what the meaning of life is, and how we should live.
59. Annila A. Neutron star characteristics from the neutron structure. *Front. Phys.* 2023, doi:10.3389/fphy.2023.1286802
The neutron structure makes sense of neutron star density, magnetism, and spinning, as well as pulsing transients.
60. Annila A, Wikström M. Quantum entanglement and classical correlation have the same form. *Eur. Phys. J. Plus* 2024 139, 560 doi: 10.1140/epjp/s13360-024-05377-8
Classical correlation explaining quantum entanglement clarifies the foundations of modern physics and quantum computing.
61. Annila A. On the origin of cognition. *Biological Theory* 2024: 1-12. https://doi.org/10.1007/s13752-024-00472-6
Data associated with cognition display the same universal characteristics, skewed distributions, sigmoid cumulative curves, power laws, suggesting that cognitive faculty originated from the universal principle of consuming free energy in the least time.
62. Annila A. Comprehensible dynamics of quanta: from the quantum of action to the 2nd law of thermodynamics. *Eur.*

Phys. J. Plus 2025 140, 28. https://doi.org/10.1140/epjp/s13360-025-05970-5.

The irreversible evolution in the state space toward thermodynamic balance explains that increasing disorder is not a law of nature itself but a consequence of the law to attain balance with incoherent surroundings in the least time.

1.2. MANUSCRIPTS

63. Annila A. Gravitational flux from the expansion explains galaxy rotation and velocity dispersion.

In place of dark matter or modified gravity, the gravitation of all ordinary matter, ranging from nearby sparse present to the distant dense past, displays itself in galaxy rotation and velocity dispersion as well as in recession.

64. Annila A. Particles as strings of quantum actions.

Elementary particle structures are determined from their characteristics, assuming that the quantum of action is the indivisible and indestructible basic building block of everything.

65. Annila A, Baverstock K. Evolution follows the 2nd law of thermodynamics.

Evolution is derived from the statistical physics of open quantized systems to account for the ubiquitous patterns in data.

1.3. EARLIER PAPERS IN PEER-REVIEWED JOURNALS

66. Oja AS, Annila AJ, Takano Y. Resplitting of Exchange-merged NMR Absorption Lines at High Spin Polarizations. *Phys Rev* B 38, 8602–8 1988.
67. Annila AJ, Clausen KN, Lindgård P-A, Lounasmaa OV, Oja AS, Siemensmeyer K, Steiner M, Tuoriniemi JT, Weinfurter H. Nuclear Order in Copper: New Type of Antiferromagnetism in an Ideal FCC System. *Phys Rev Lett* 64, 1421–4 1990.
68. Oja AS, Annila AJ, Takano Y. Cross Relaxation by Single Spin Flips in Silver at Nanokelvin Temperatures. *Phys Rev Lett* 65, 1921–4 1990.
69. Annila AJ, Clausen KN, Lindgård P-A, Lounasmaa OV, Oja AS, Siemensmeyer K, Steiner M, Tuoriniemi JT, Weinfurter H. Nuclear Order in Copper: New type of Antiferromagnetism in an Ideal FCC System. *Physica B* 165, 779–80 1990.
70. Annila AJ, Clausen KN, Oja AS, Siemensmeyer K, Tuoriniemi JT, Weinfurter H. Nuclear Antiferromagnetic Phases of Copper in a Field. *Physica B* 165, 781–2 1990.
71. Annila AJ, Clausen KN, Oja AS, Siemensmeyer K, Steiner M, Tuoriniemi JT, Weinfurter H. Kinetics, Hysteresis and Nonadiabaticity of the Phase Transitions in the Nuclear Spin System of Copper. *Physica B* 165, 783–4 1990.
72. Annila AJ, Clausen KN, Oja AS, Tuoriniemi JT, Weinfurter H. Neutron Diffraction Studies of the Nuclear Phase Diagram of Copper. *Phys Rev* B 45, 7772–88 1991.
73. Oja AS, Annila AJ, Takano Y. Investigations of Nuclear Magnetism in Silver Down to Picokelvin Temperatures I. *J Low Temp Phys* 85, 1–24 1991.
74. Siemensmeyer K, Steiner M, Weinfurter H, Clausen KN, Lindgård P-A, Annila AJ, Lounasmaa OV, Oja AS, Tuoriniemi JT, The Phase-Diagram and the Magnetic-structure of Nuclear Spins in Elemental Copper below 60 nK. *Physica B* 180, 29–30 1992.
75. Matikainen J, Kaltia S, Hase T, Kilpeläinen I, Drakenberg T, Annila A. Semipreparative Synthesis, ^{13}C and 2D-NMR of Puloupones. *Tetrahedron* 49, 8007–14 1993.
76. Toba M, Mizukami F, Niwa S, Sano T, Maeda K, Annila A, Komppa V. The effect of Preparation Methods on Properties of Titania&Aluminas. *J Mat Chem* 4, 585–9 1994.
77. Toba M, Mizukami F, Niwa S, Sano T, Maeda K, Annila A, Komppa V. Effect of the Type of Preparation on the Properties of Titania/Silicas. *J Mol Catal* 91, 277–89 1994.
78. Toba M, Mizukami F, Niwa S, Sano T, Maeda K, Annila A, Komppa V. Effect of the Type of Preparation on the Properties of Zirconia/Silicas. *J Mol Catal* 94, 85–96 1994.
79. Linder M, Mattinen M-L, Kontteli M, Reinikainen T, Pettersson G, Lindeberg G, Drakenberg T, Annila A.Identification of Functionally Important Amino Acids in the Cellulose Binding Domains of *Trichoderma reesei* Cellobiohydrolase I. *Protein Sci* 4, 1056–64 1995.
80. Sellin LC, Mattila K, Annila A, Schmidt JJ, McArdle JJ, Hyvönen M, Rantala TT, Kivistö T. Conformational Analysis of a Toxic Peptide from *T. wagleri* which Blocks the Nicotinic Acetylcholine Receptor. *Biophys J* 70, 3–13 1996.
81. Paananen K, Saarinen J, Annila A, Kovanen PT. Proteolysis and Fusion of Low Density Lipoprotein Particles Strengthen Their Binding to Human Aortic Proteoglycans. *J Biol Chem* 270, 12257–62 1995.
82. Trogen T, Annila A, Eriksson JE, Kontteli M, Meriluoto J, Sethson I, Zdunek J, Edlund U. Conformational Studies of Microcystin-LR using NMR Spectroscopy and Molecular Dynamics Calculations. *Biochemistry* 35, 3197–205 1996.
83. Annila A, Lehtimäki J, Mattila K, Eriksson JE, Sivonen K, Rantala TT, Drakenberg T. Solution Structure of Nodularin - An Inhibitor of Serine/Threonine-specific Protein Phosphatases. *J Biol Chem* 271, 16695–702 1996.
84. Mattinen ML, Kontteli M, Kerovuo J, Linder M, Annila A, Lindeberg G, Reinikainen T, Drakenberg T. Three-dimensional Structures of Three Engineered Cellulose Binding Domains. *Protein Sci* 6, 294–303 1996.
85. Öörni K, Hakala JK, Annila A, Kovanen PT. Modification of LDL with phospholipase A2 generates aggregated and fused particles with increased strength of binding to proteoglycans. *Atherosclerosis* 134, 225–6 1997.
86. Öörni K, Pentikäinen MO, Annila A, Kovanen PT. Oxidation of Low Density Lipoprotein Particles Decreases Their Ability to Bind to Human Aortic Proteoglycans. Dependence on Oxidative Modification of the Lysine Residues. *J Biol Chem* 272, 21303–11 1997.
87. Mattinen ML, Linder M, Teleman A, Annila A. Interaction of Cellohexaose with Cellulose Binding Domains from *Trichoderma reesei. FEBS Lett* 407, 291–6 1997.

88. Ala-Korpela M, Hyvonen MT, Pentikainen MO, Hevonoja T, Oorni K, Korhonen A, Annila A, Lounila J, Kovanen PT. Molecular characteristics of low density lipoprotein particle fusion. *Biophys J* 74, A298 1998.
89. Mattinen M-L, Linder M, Drakenberg T, Annila A. Solution Structure of the Cellulose-binding Domain of Endoglucanase I from *Trichoderma reesei*. *Eur J Biochem* 256, 279–86 1998.
90. Pollesello P, Annila A, Ovaska M. Structure of the 1-36 amino-terminal Fragment of Human Phospholamban by Nuclear Magnetic Resonance and Modeling of the Phospholamban Pentamer. *Biophys J* 76, 1784–95 1999.
91. Pääkkönen K, Annila A, Pollesello P, Tilgman C, Sorsa T, Karisola P, Kilpeläinen I, Ulmanen I, Drakenberg T. Solution Structure and Main-chain Dynamics of the Regulatory Domain (aa 1-91) of Human Cardiac Troponin C. *J Biol Chem* 273, 15633–38 1998.
92. Anderson P, Annila A, Otting G. An Experiment for Spin-State Selective Editing of IS Cross Peaks. *J Magn Reson* 133, 364–7 1998.
93. Öörni K, Hakala JK, Annila A, Ala-Korpela M, Kovanen PT. Sphingomyelinase Induces Aggregation and Fusion but Phospholiase A2 Only Aggregation, of Low Density Lipoprotein Particles. *J Biol Chem* 273, 29127–34 1998.
94. Permi P, Heikkinen S, Kilpeläinen I, Annila A. Measurement of Homonuclear ^2J-Couplings from Spin-State Selective Double-/Zero-Quantum Two-Dimensional NMR Spectra. *J Magn Reson* 139, 273–80 1999.
95. Annila A, Aitio H, Thulin E, Drakenberg T. Recognition of Protein Folds via Dipolar Couplings. *J Biol NMR* 14, 223–30 1999.
96. Permi P, Heikkinen S, Kilpeläinen I, Annila A. Measurement of $^1J_{NC'}$ and $^2J_{HNC'}$ Couplings from Spin-State Selective Two-Dimensional [^{15}N,^{1}H] Correlation Spectrum. *J Magn Reson* 140, 32–40 1999.
97. Permi P, Sorsa T, Kilpeläinen I, Annila A. HN(α/β-COCA-*J*) Experiment for Measurement of $^1J_{C'C\alpha}$ Couplings from Two-Dimensional [^{15}N, ^{1}H] Correlation Spectrum. *J Magn Reson* 141, 3–13 1999.
98. Aitio H, Annila A, Thulin E, Drakenberg T, Kilpeläinen I. Secondary Structure and Fold of Calerythrin, an EF-hand Calcium-binding Protein from *Saccharopolyspora erythreae. Protein Sci* 8, 2580–8 1999.
99. Levijoki J, Pollesello P, Kaivola J, Tilgmann C, Sorsa T, Annila A, Kilpeläinen I, Haikala H. Further Evidence for the Cardiac Troponin C Mediated Calcium Sensitization by Levosimendan: Structure-response and Binding Analysis with Analogs of Levosimendan. *J Mol Cell Cardiol* 32, 479–91 2000.
100. Permi P, Kilpeläinen I, Annila A. Heikkinen S. Intensity Modulated HSQC and HMQC: Two Simple Methods to Measure $^3J_{NHH}$ in Proteins. *J Biomol NMR* 16, 29–37 2000.
101. Permi P, Annila A. Transverse Relaxation Optimised Spectroscopy for Measurement of Residual Dipolar Couplings from Two-Dimensional [^{15}N, ^{1}H] Correlation Spectra. *J Biomol NMR* 16, 221–227 2000.
102. Permi P, Rosewear PR, Annila A. A Set of HNCO-TROSY Based Experiments for Measurement of Scalar and Dipolar Couplings. *J Biomol NMR* 17, 43–54 2000.
103. Pääkkönen K, Sorsa T, Drakenberg T, Pollesello P, Tilgmann C, Permi P, Heikkinen S, Kilpeläinen I, Annila A. Conformational Changes of Cardiac Troponin C Examined by Residual Dipolar Couplings. *Eur J Biochem* 267, 6665–72 2000.
104. Permi P, Kilpeläinen I, Annila A. Determination of Main Chain Dihedral Angle in Proteins Using a TROSY-BASED / -HN(CO)CA-*J* Experiment. *J Magn Reson* 146, 255–9 2000.
105. Permi P, Annila A. Sequential Assignment from Two-dimensional Inter and Intra Residue [^{15}N, ^{1}H] Correlation Spectra. *Magn Reson Chem* 39, 179–81 2001.
106. Koivunen E, Ranta T-M, Annila A, Taube S, Uppala A, Jokinen M, Ihanus W, Gahmberg CG. Inhibition of integrin-mediated leukocyte cell adhesion by leu-leu-gly motif-containing peptides. *J Cell Biology* 153, 905–16 2001.
107. Aitio H, Laakso T, Pihlajamaa T, Torkkeli M, Kilpelainen I, Drakenberg T, Serimaa R, Annila A. Characterization of apo and partially saturated states of calerythrin, an EF-hand protein from *S. erythraea*: a molten globule when deprived of Ca(2+). *Protein Sci* 10, 74–82 2001.
108. Sorsa T, Heikkinen S, Abbott MB, Abusamhadneh E, Laakso T, Tilgmann C, Serimaa R, Annila A, Rosevear PR, Drakenberg T, Pollesello P, Kilpeläinen I. Binding of levosimendan, a calcium sensitizer, to cardiac troponin C. *J Biol Chem* 276, 9337–43 2001.
109. Permi P, Annila A. A new approach for obtaining sequential assignment of large proteins. *J Biomol NMR* 20, 127–33 2001.
110. Pollesello P, Annila A. Structure of the 1-36 N-terminal Fragment of Human Phospholamban Phosphorylated at Ser16 and Thr17: an NMR study. *Biophys J* 83, 484–90 2002.
111. Mattinen M, Pääkkönen K, Ikonen T, Drakenberg T, Craven J, Serimaa R, Waltho J, Annila A. Quaternary structure built from subunits combining NMR and small-angle x-ray scattering data. *Biophys J* 83, 1177–83 2002.
112. Permi P, Annila A. Evaluation and optimization of coherence transfer in high molecular weight systems. *J Magn Reson* 155, 123–30 2002.
113. Schmidt AG, Zhai J, Carr AN, Gerst MJ, Lorenz JN, Pollesello P, Annila A, Hoit BD, Kranias EG. Structural and functional implications of the phospholamban hinge domain: impaired SR Ca2+ uptake as a primary cause of heart failure. *Cardiovasc Res* 56, 248–59 2002.
114. Tossavainen H, Permi P, Annila A, Kilpeläinen I, Drakenberg T. NMR solution structure of calerythrin, an EF-hand calcium-binding protein from *Saccharopolyspora erythraea*. *Eur J Biochem* 270, 2505–12 2003.
115. Louhivuori M, Pääkkönen K, Fredriksson K, Permi P, Lounila J, Annila A. On the origin of residual dipolar couplings from denatured proteins. *J Am Chem Soc* 125, 15647–50 2003.
116. Louhivuori M, Fredriksson K, Pääkkönen K, Permi P, Annila A. Alignment of chain-like molecules. *J Biomol NMR* 29, 517–24 2004.
117. Fredriksson K, Louhivuori M, Permi P, Annila A. On the interpretation of residual dipolar couplings as reporters of molecular dynamics. *J Am Chem Soc* 126, 12646–50 2004.
118. Annila A, Permi P. Weakly aligned biological macromolecules in dilute liquid crystals. *Concepts in Magn Reson* 23, 22–37 2004.

119. Permi P, Annila A. Coherence transfer in proteins. *Progr Nucl Magn Reson* 44, 97–137 2004.
120. Hellman M, Paavilainen V O, Naumanen P, Lappalainen P, Annila A, Permi P. Solution structure of coactosin reveals structural homology to ADF/cofilin family proteins. *FEBS Lett* 576, 91–6 2004.
121. Hellman M, Paavilainen V, Annila A, Lappalainen P, Permi P. (1)H, (13)C and (15)N resonance assignments of coactosin, a cytoskeletal regulatory protein. *J Biomol NMR* 3, 365–6 2004.
122. Medina OP, Kairemo K, Valtanen H, Kangasniemi A, Kaukinen S, Ahonen I, Permi P, Annila A, Sneck M, Holopainen JM, Karonen SL, Kinnunen PK, Koivunen E. Radionuclide imaging of tumor xenografts in mice using a gelatinase-targeting peptide. *Anticancer Res* 25(1A), 33–42 2005.
123. Trevitt CR, Craven CJ, Milanesi L, Syson K, Mattinen ML, Perkins J, Annila A, Hunter CA, Waltho JP. Enhanced ligand affinity for receptors in which components of the binding site are independently mobile. *Chem Biol* 12, 89–97 2005.
124. Drakenberg T, Ghasriani H, Thulin E, Thamlitz AM, Muranyi A, Annila A, Stenflo J. Solution structure of the Ca^{2+}-Binding EGF3-4 pair from vitamin K-dependent protein S: identification of an unusual fold in EGF3. *Biochemistry* 44, 8782–9 2005.
125. Louhivuori M, Otten R, Linddorf-Larsen K, Annila A. Conformational fluctuations affect protein alignment in dilute liquid crystal media. *J Am Chem Soc* 128, 4371–6 2006.
126. Zhao W, Yuan Q, Qian J, Waggoner JR, Pathak A, Chu G, Mitton B, Sun X, Jin J, Braz JC, Hahn HS, Marreez Y, Syed F, Pollesello P, Annila A, Wang HS, Schultz Jel J, Molkentin JD, Liggett SB, Dorn GW 2nd, Kranias EG. The presence of Lys27 instead of Asn27 in human phospholamban promotes sarcoplasmic reticulum Ca2+-ATPase superinhibition and cardiac remodeling. *Circulation* 113, 995–1004 2006.
127. von Ossowski L, Tossavainen H, von Ossowski I, Cai C, Aitio O, Fredriksson K, Permi P, Annila A, Keinänen K. Peptide binding and NMR analysis of the interaction between SAP97 PDZ2 and GluR-A: potential involvement of a disulfide bond. *Biochemistry* 45, 5567–75 2006.
128. Hellman M, Paavilainen VO, Annila A, Lappalainen P, Permi P. NMR assignment of the C-terminal ADF-H domain of an actin monomer binding protein, twinfilin. *J Biomol NMR* 36 Suppl 5:66 2006.
129. Paavilainen VO, Hellman M, Bovellan M, Helfer E, Annila A, Carlier M-F, Permi P, Lappalainen P. Structural basis and evolutionary origin of actin filament capping by twinfilin. *Proc Natl Acad Sci* 104, 3113–8 2007.
130. Louhivuori M, Otten R, Salminen T, Annila A. Evidence of molecular alignment fluctuations in aqueous dilute liquid crystalline media. *J Biomol NMR* 39, 141–52 2007.
131. Würtz P, Permi P, Nielsen NC, Sørensen OW and Annila, A. Clean HMBC: Suppression of strong-coupling induced artifacts in HMBC spectra. *J Magn Reson* 194, 89–98 2008.
132. Tilgmann C, Pollesello P, Ovaska M, Kaivola J, Pystynen J, Tiainen E, Yliperttula M, Annila A, Levijoki J. Discovery and Structural Characterization of a Phospholamban-Binding Cyclic Peptide and Design of Novel Inhibitors of Phospholamban. *Chem Biol Drug Des* 81, 463–73 2013.

1.4. OTHER PUBLICATIONS (IN FINNISH FOR GENERAL AUDIENCE)

133. Annila A. Informaation olemus. *Signum* 4, 2011.
134. Annila A. Luonnonlain luonne. *Tieteessä tapahtuu* 32, 20–23 2014.
135. Annila A. Ennustamisen vaikeus. *Tieteessä tapahtuu* 32, 51–52 2014.
136. Annila A. Nykyteoriain vajavaisuuksien syistä. *Tieteessä tapahtuu* 34, 56–57 2016.

1.5. PREPRINTS

Some original manuscripts can be found in arXiv, ResearchGate, and Google Scholar.

1.6. BOOK

The book, *Back to Reality: A Revision of the Scientific Worldview* (Privus Press, 2020), a translation of the original work in Finnish: *Kaiken maailman kvantit, luonnontieteen maailmankuvan tarkistus* (Vastapaino, 2019), communicate a comprehensive worldview based on the statistical physics of open quantized systems.