

**Dierckx, Hans; Arens, Sander; Li, Bing-Wei; Weise, Louis D.; Panfilov, Alexander V.**  
**A theory for spiral wave drift in reaction-diffusion-mechanics systems.** (English)

Zbl 1452.35076

New J. Phys. 17, No. 4, Article ID 043055, 20 p. (2015).

**MSC:**

35K57 Reaction-diffusion equations

**Keywords:**

electromechanical coupling; cardiac modeling; spiral waves; mechano-electrical feedback; stretch-activated currents; spiral wave drift; resonant drift

**Full Text:** [DOI](#)

**References:**

- [1] Zhabotinsky A M and Zaikin A N 1973 Autowave processes in a distributed chemical system \textit{J. Theor. Biol.}40 45-61. doi:10.1016/0022-5193(73)90164-1
- [2] Jacubith S, Rotermund H H, Engel W, von Oertzen A and Ertl G 1990 Spatiotemporal concentration patterns in a surface-reaction—propagating and standing waves, rotating spirals and turbulence \textit{Phys. Rev. Lett.}65 3013-6. doi:10.1103/PhysRevLett.65.3013
- [3] Siegert F and Weijer C J 1992 Three dimensional scroll waves organize dictyostelium slugs \textit{Proc. Natl. Acad. Sci. USA}89 6433-7. doi:10.1073/pnas.89.14.6433
- [4] Dahlem M A and Müller S C 2004 Reaction-diffusion waves in neuronal tissue and the window of cortical excitability \textit{Ann. Phys., Lpz.}13 442-9 · Zbl 1072.92022 · doi:10.1002/andp.200410087
- [5] Allesie M A, Bonke F I M and Schopman F J G 1973 Circus movement in rabbit atrial muscle as a mechanism of tachycardia \textit{Circ. Res.}33 54-62. doi:10.1161/01.RES.33.1.54
- [6] Davidenko J M, Pertsov A M, Salomontsz R, Baxter W and Jalife J 1992 Stationary and drifting spiral waves of excitation in isolated cardiac muscle \textit{Nature}355 349-51. doi:10.1038/355349a0
- [7] Rudenko A N and Panfilov A V 1983 Drift and interaction of vortices in two-dimensional heterogeneous active medium \textit{Stud. Biophys.}98 183-8
- [8] Panfilov A V and Vasiev B N 1991 Vortex initiation in a heterogeneous excitable medium \textit{Physica} D 49 107-13. doi:10.1016/0167-2789(91)90200-S
- [9] Agladze K I, Davydov V A and Mikhailov A S 1987 An observation of resonance of spiral waves in distributed excitable medium \textit{JETP Lett.}45 767-9
- [10] Wellner M, Berenfeld O and Pertsov A M 2000 Predicting filament drift in twisted anisotropy \textit{Phys. Rev.} E 61 1845-50. doi:10.1103/PhysRevE.61.1845
- [11] Dierckx H, Brisard E, Verschelde H and Panfilov A V 2013 Drift laws for spiral waves on curved anisotropic surfaces \textit{Phys. Rev.} E 88 012908. doi:10.1103/PhysRevE.88.012908
- [12] Gray R A, Jalife J, Panfilov A, Baxter W T, Cabo C and Pertsov A M 1995 Non-stationary vortex-like reentrant activity as a mechanism of polymorphic ventricular tachycardia in the isolated rabbit heart \textit{Circulation}91 2454-69. doi:10.1161/01.CIR.91.9.2454
- [13] Yashin V V and Balazs A C 2006 Pattern formation and shape changes in self-oscillating polymer gels \textit{Science}314 798-801. doi:10.1126/science.1132412
- [14] Radszweit M, Engel H and Baer M 2014 An active poroelastic model for mechanochemical patterns in protoplasmic droplets of physarum polycephalum \textit{PLoS ONE}9 e99220. doi:10.1371/journal.pone.0099220
- [15] Kohl P, Hunter P and Noble D 1999 Stretch-induced changes in heart rate and rhythm: clinical observations, experiments and mathematical models \textit{Prog. Biophys. Mol. Biol.}71 91-138. doi:10.1016/S0079-6107(98)00038-8
- [16] Hu H and Sachs F 1997 Stretch-activated ion channels in the heart \textit{J. Mol. Cell. Cardiol.}29 1511-23. doi:10.1006/jmcc.1997.0392
- [17] Nash M P and Panfilov A V 2004 Electromechanical model of excitable tissue to study reentrant cardiac arrhythmias \textit{Prog. Biophys. Mol. Biol.}85 501-22. doi:10.1016/j.pbiomolbio.2004.01.016
- [18] Panfilov A V, Keldermann R H and Nash M P 2005 Self-organized pacemakers in a coupled reaction-diffusion-mechanics system \textit{Phys. Rev. Lett.}95 258104. doi:10.1103/PhysRevLett.95.258104
- [19] Panfilov A V, Keldermann R H and Nash M P 2007 Drift and breakup of spiral waves in reaction-diffusion-mechanics systems \textit{Proc. Nat. Acad. Sci. USA}104 7922-6. doi:10.1073/pnas.0701895104

- [20] Weise L D and Panfilov A V 2013 A discrete electromechanical model for human cardiac tissue: effects of stretch-activated currents and stretch conditions on restitution properties and spiral wave dynamics \textit{PLoS ONE} 8 e59317 · doi:10.1371/journal.pone.0059317
- [21] Weise L D and Panfilov A V 2012 Emergence of spiral wave activity in a mechanically heterogeneous reaction-diffusion-mechanics system \textit{Phys. Rev. Lett.} 108 228104 · doi:10.1103/PhysRevLett.108.228104
- [22] Cherubini C, Filippi S and Gizzi A 2012 Electroelastic unpinning of rotating vortices in biological excitable media \textit{Phys. Rev. E} 85 031915 · doi:10.1103/PhysRevE.85.031915
- [23] Biktasheva I V and Biktashev V N 2003 Wave-particle dualism of spiral wave dynamics \textit{Phys. Rev. E} 67 026221 · doi:10.1103/PhysRevE.67.026221
- [24] Weise L D, Nash M P and Panfilov A V 2011 A discrete model to study reaction-diffusion-mechanics systems \textit{PLoS ONE} 6 e21934 · doi:10.1371/journal.pone.0021934
- [25] Weise L D and Panfilov A V 2011 New mechanism of spiral wave initiation in a reaction-diffusion-mechanics system \textit{PLoS ONE} 6 e27264 · doi:10.1371/journal.pone.0027264
- [26] Aliev R R and Panfilov A V 1996 A simple two-variable model of cardiac excitation \textit{Chaos Solitons Fractals} 7 293-301 · doi:10.1016/0960-0779(95)00089-5
- [27] Keldermann R H, Nash M P, Gelderblom H, Wang V Y and Panfilov A V 2010 Electromechanical wavebreak in a model of the human left ventricle \textit{Am. J. Physiol. Heart Circ. Physiol.} 299 134-43 · doi:10.1152/ajpheart.00862.2009
- [28] Zhang Y, Youm J, Sung H, Lee S, Ryu S, Ho W and Earm Y 2000 Stretch-activated and background non-selective cation channels in rat atrial myocytes \textit{J. Physiol.} 523 607-19 · doi:10.1111/j.1469-7793.2000.00607.x
- [29] Trayanova N, Li W, Eason J and Kohl P 2004 Effect of stretch activated channels on defibrillation efficacy \textit{Heart Rhythm} 1 67-77 · doi:10.1016/j.hrthm.2004.01.002
- [30] Vetter F and Culloch A 2001 Mechanoelectric feedback in a model of the passively inflated left ventricle \textit{Ann. Biomed. Eng.} 29 414-26 · doi:10.1114/1.1366670
- [31] Keener J P 1988 The dynamics of three-dimensional scroll waves in excitable media \textit{Physica} D 31 269-76 · Zbl 0645.76052 · doi:10.1016/0167-2789(88)90080-2
- [32] Biktashev V N and Holden A V 1995 Resonant drift of autowave vortices in two dimensions and the effect of boundaries and inhomogeneities \textit{Chaos Solitons Fractals} 5 575-562 · Zbl 0925.92022 · doi:10.1016/0960-0779(93)E0044-C
- [33] Biktasheva I V, Elkin Y E and Biktashev V N 1998 Localized sensitivity of spiral waves in the complex ginzburg-landau equation \textit{Phys. Rev. E} 57 2656-9 · doi:10.1103/PhysRevE.57.2656
- [34] Biktashev V N, Holden A V and Zhang H 1994 Tension of organizing filaments of scroll waves \textit{Phil. Trans. R. Soc. Lond. A} 347 611-30 · Zbl 0862.92002 · doi:10.1098/rsta.1994.0070
- [35] Henry H and Hakim V 2000 Linear stability of scroll waves \textit{Phys. Rev. Lett.} 85 5328-31 · doi:10.1103/PhysRevLett.85.5328
- [36] Henry H and Hakim V 2002 Scroll waves in isotropic excitable media: linear instabilities, bifurcations, and restabilized states \textit{Phys. Rev. E} 65 046235 · Zbl 1244.35071 · doi:10.1103/PhysRevE.65.046235
- [37] Henry H 2004 Spiral wave drift in an electrical field and scroll wave instabilities \textit{Phys. Rev. E} 70 026204 · doi:10.1103/PhysRevE.70.026204
- [38] Vershelde H, Dierckx H and Bernus O 2007 Covariant stringlike dynamics of scroll wave filaments in anisotropic cardiac tissue \textit{Phys. Rev. Lett.} 99 168104 · doi:10.1103/PhysRevLett.99.168104
- [39] Dierckx H, Bernus O and Vershelde H 2009 A geometric theory for scroll wave filaments in anisotropic excitable tissue \textit{Phys. D} 238 941-50 · Zbl 1185.37187 · doi:10.1016/j.physd.2008.09.006
- [40] Dierckx H and Vershelde H 2013 Effective dynamics of twisted and curved scroll waves using virtual filaments \textit{Phys. Rev. E} 88 062907 · doi:10.1103/PhysRevE.88.062907
- [41] Biktasheva I V, Holden A V and Biktashev V N 2006 Localization of response functions of spiral waves in the fitzhugh-nagumo system \textit{Int. J. Bifurcation Chaos} 16 1547-55 · Zbl 1145.35399 · doi:10.1142/S0218127406015490
- [42] Biktasheva I V, Barkley D, Biktashev V N, Bordyugov G V and Foulkes A J 2009 Computation of the response functions of spiral waves in active media \textit{Phys. Rev. E} 79 056702 · doi:10.1103/PhysRevE.79.056702
- [43] Barkley D 1992 Linear stability analysis of rotating spiral waves in excitable media \textit{Phys. Rev. Lett.} 68 2090-3 · doi:10.1103/PhysRevLett.68.2090
- [44] Zykov V S 1987 \textit{Simulation of Wave Processes in Excitable Media} (Manchester: Manchester University Press)
- [45] Dierckx H, Bernus O and Vershelde H 2011 Accurate eikonal-curvature relation for wave fronts in locally anisotropic reaction-diffusion systems \textit{Phys. Rev. Lett.} 107 108101 · doi:10.1103/PhysRevLett.107.108101
- [46] Strogatz S H 1994 \textit{Nonlinear Dynamics and Chaos: With Applications to Physics, Biology Chemistry and Engineering} (Reading, MA: Addison Wesley)
- [47] England A H 2003 \textit{Complex Variable Methods in Elasticity} (New York: Wiley)
- [48] Zykov V S and Engel H 2004 Dynamics of spiral waves under global feedback in excitable domains of different shapes \textit{Phys. Rev. E} 70 016201 · doi:10.1103/PhysRevE.70.016201
- [49] Nanthakumar K, Walcott G P, Melnick S, Rogers J M, Kay M W, Smith W M, Ideker R E and Holman W 2004 Epicardial organization of human ventricular fibrillation \textit{Heart Rhythm} 1 14-23 · doi:10.1016/j.hrthm.2004.01.007
- [50] Pertsov A M, Davidenko J M, Salomontsz R, Baxter W and Jalife J 1993 Spiral waves of excitation underlie reentrant activity in isolated cardiac muscle \textit{Circ. Res.} 72 631-50 · doi:10.1161/01.RES.72.3.631
- [51] Nanthakumar K \textit{et al} 2007 Optical mapping of langendorff-perfused human hearts: establishing a model for the study

of ventricular fibrillation in humans \textit{AJP: Heart Circulatory Physiol.}293 875-80· doi:10.1152/ajpheart.01415.2006

- [52] Winfree A T 1987 \textit{When Time Breaks Down} (Princeton, NJ: Princeton University Press)
- [53] Alvarez-Lacalle E and Echebarria B 2009 Global coupling in excitable media provides a simplified description of mechano-electrical feedback in cardiac tissue \textit{Phys. Rev.} E 79 031921· doi:10.1103/PhysRevE.79.031921
- [54] Zykov V S and Engel H 2004 Feedback-mediated control of spiral waves \textit{Phys.} D 199 243-63 · Zbl 1067.92003 · doi:10.1016/j.physd.2004.10.001
- [55] Zykov V S, Bordiougov G, Brandtstadter H, Gerdes I and Engel H 2004 Global control of spiral wave dynamics in an excitable domain of circular and elliptical shape \textit{Phys. Rev. Lett.}92 018304· doi:10.1103/PhysRevLett.92.018304
- [56] Zykov V S, Brandtstadter H, Bordiougov G and Engel H 2005 Interference patterns in spiral wave drift induced by a two-point feedback \textit{Phys. Rev.} E 72 065201· doi:10.1103/PhysRevE.72.065201
- [57] Camelliti P, Gallagher J O, Kohl P and McCulloch A D 2006 Micropatterned cell cultures on elastic membranes as an in vitro model of myocardium \textit{Nat. Protocols}1 1379-91· doi:10.1038/nprot.2006.203
- [58] Narayan S M, Krummen D E, Shivkumar K, Clopton P, Rappel W-J and Miller J M 2012 Treatment of atrial fibrillation by the ablation of localized sources \textit{J. Am. Coll. Cardiol.}60 628-36· doi:10.1016/j.jacc.2012.05.022

This reference list is based on information provided by the publisher or from digital mathematics libraries. Its items are heuristically matched to zbMATH identifiers and may contain data conversion errors. It attempts to reflect the references listed in the original paper as accurately as possible without claiming the completeness or perfect precision of the matching.