

# Recent Developments in Weak Convergence Methods for Nonlinear PDE

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Lawrence C. Evans  
Department of Mathematics  
University of California, Berkeley

In memory of Ron DiPerna, *il miglior fabbro*.

## References

- [E1] L. C. Evans, *Weak Convergence Methods for Nonlinear Partial Differential Equations*, CBMS #74, American Mathematical Society, 1990. Third printing, 2002.

## CONVEXITY METHODS

- [Am] L. Ambrosio, Lecture notes on optimal transport problems, in *Mathematical Aspects of Evolving Interfaces*, Lecture Notes in Math, 1812, Springer, 2003, 1–52
- [A-G-S] L. Ambrosio, N. Gigli and G. Savare, *Gradient Flows in Metric Spaces and in the Space of Probability Measures*, Lectures in Mathematics ETH Zürich, Birkhäuser 2005.
- [Ar] G. Aronsson, A mathematical model in sand mechanics, *SIAM J. Applied Math*, 22 (1972), 437–458.

- [A-E-W] G. Aronsson, L. C. Evans and Y. Wu, Fast/slow diffusion and growing sandpiles, *Journal of Differential Equations* 131 (1996), 304–335.
- [B-J-W] E. N. Barron, R. Jensen and C. Y. Wang, The Euler equation and absolute minimizers of  $L^\infty$  functionals, *Arch. Ration. Mech. Analysis* 157 (2001), 255–283.
- [D-M1] B. Dacorogna and P. Marcellini, *Implicit Partial Differential Equations*, Progress in Nonlinear Differential Equations and their Applications, 37, Birkhäuser, 1999.
- [D-M2] B. Dacorogna and P. Marcellini, Implicit second order partial differential equations, *Ann. Scuola Norm. Sup. Pisa Cl. Sci.* 25 (1998), 299–328.
- [D-M3] B. Dacorogna and P. Marcellini, General existence theorems for Hamilton-Jacobi equations in the scalar and vectorial cases, *Acta Math.* 178 (1997), 1–37.
- [DM-F-T] G. Dal Maso, G. Francfort and R. Toader, Quasistatic crack growth in nonlinear elasticity, *Arch. Ration. Mech. Analysis* 176 (2005), 165–225.
- [E2] L. C. Evans, Partial differential equations and Monge-Kantorovich mass transfer, in *Current Developments in Mathematics, 1997*, edited by S. T. Yau, International Press (1999), 26–79. Latest version: [math.berkeley.edu/~evans/Monge-Kantorovich.survey.pdf](http://math.berkeley.edu/~evans/Monge-Kantorovich.survey.pdf)
- [E3] L. C. Evans, Three singular variational problems, in *Viscosity Solutions of Differential Equations and Related Topics*, Research Institute for the Mathematical Sciences, RIMS Kokyuroku 1323, 2003.
- [E4] L. C. Evans, An unusual minimization principle for parabolic gradient flows, *SIAM Journal of Mathematical Analysis* 27 (1996), 1–4.
- [E-G-S] L. C. Evans, W. Gangbo and O. Savin, Diffeomorphisms and nonlinear heat flows, *SIAM J. Math. Analysis* 37 (2005), 737–751.
- [E-G1] L. C. Evans and D. Gomes, Effective Hamiltonians and averaging for Hamiltonian dynamics I, *Archive for Rational Mechanics and Analysis* 157 (2001), 1–33.
- [E-G2] L. C. Evans and D. Gomes, Linear programming interpretations of Mather’s variational principle, in *A Tribute to Jacques-Louis Lions*, Tome 2, Control, Optimisation and Calculus of Variations 8 (2002).

- [F] A. Fathi, *Weak KAM Theory in Lagrangian Dynamics*, book to appear.
- [F-S] A. Fathi and A. Siconolfi, PDE aspects of Aubry-Mather theory for quasiconvex Hamiltonians, *Calc. Var. Partial Differential Equations* 22 (2005), 185–228.
- [F-M] G. Forni and J. Mather, Action minimizing orbits in Hamiltonian systems in *Transition to Chaos in Classical and Quantum Mechanics*, Lecture Notes in Math 1589, ed by S. Graffi, Springer, 1994.
- [G] M. Gromov, *Partial Differential Relations*, Springer, 1986.
- [I-L] H. Ishii and P. Loreti, Relaxation of Hamilton-Jacobi equations, *Arch. Ration. Mech. Analysis* 169 (2003), 265–304.
- [J-K-O] R. Jordan, D. Kinderlehrer, and F. Otto, The variational formulation of the Fokker–Planck equation, *SIAM J. Math. Analysis* 29 (1998), 1–17.
- [K-P] D. Kinderlehrer and P. Pedregal, Characterizations of Young measures generated by gradients, *Arch. Rational Mech. Analysis* 115 (1991), 329–365.
- [Kr] B. Kirchheim, *Rigidity and Geometry of Microstructures*, lecture notes.
- [K-M-S] B. Kirchheim, S. Müller and V. Sverak, Studying nonlinear PDE by geometry in matrix space, in *Geometric Analysis and Nonlinear Partial Differential Equations*, 347–395, Springer, 2003.
- [Ky] N. V. Krylov, Some properties of monotone mappings (Russian), *Litovsk. Mat. Sb.* 22 (1982), 80–87.
- [Ma] J. Mather, Minimal measures, *Comment. Math Helvetici* 64 (1989), 375–394
- [MC] R. McCann, A convexity theory of interacting gases, *Advances in Mathematics* 128 (1997), 153–179.
- [M-S1] S. Müller and V. Sverak, Convex integration for Lipschitz mappings and counterexamples to regularity, *Ann. of Math.* 157 (2003), 715–742.
- [M-Sy] S. Müller and M. A. Sychev, Optimal existence theorems for nonhomogeneous differential inclusions, *J. Funct. Analysis* 181 (2001), 447–475.
- [Ot] F. Otto, The geometry of dissipative evolution equations: the porous medium equation, *Comm. Partial Differential Equations* 26 (2001), 101–174.
- [Pr] L. Prigozhin, Sandpiles and river networks: extended systems with nonlocal interactions, *Phys. Rev E* 49 (1994), 1161–1167.

- [Sy] M. A. Sychev, Comparing two methods of resolving homogeneous differential inclusions, *Calc. Var. Partial Differential Equations* 13 (2001), 213–229.
- [V] C. Villani, *Topics in Optimal Transportation*, Graduate Studies in Mathematics 58, American Mathematical Society, Providence, RI, 2003.
- [Z1] K. Zhang, Remarks on quasiconvexity and stability of equilibria for variational integrals, *Proc. Amer. Math. Soc.* 114 (1992), 927–930.
- [Z2] K. Zhang, On the principle of controlled  $L^\infty$  convergence implies almost everywhere convergence for gradients, to appear.

## OSCILLATIONS AND CANCELLATION

- [A-M] G. Alberti and S. Müller, A new approach to variational problems with multiple scales, *Comm. Pure Appl. Math.* 54 (2001), 761–825.
- [A] G. Allaire, Homogenization and two-scale convergence, *SIAM J. Math. Analysis* 23 (1992), 1482–1518.
- [A-C-P-S-V] G. Allaire, Y. Capdeboscq, A. Piatnitski, V. Siess and M. Vanninathan, Homogenization of periodic systems with large potentials, *Arch. Ration. Mech. Analysis* 174 (2004), 179–220.
- [A-O] G. Allaire and R. Orive, Homogenization of periodic non self-adjoint problems with large drift and potential, preprint.
- [A-P] G. Allaire and A. Piatnitski, Homogenization of the Schrödinger equation and effective mass theorems, *Comm. Math. Phys.* 258 (2005), 1–22.
- [A-B] O. Alvarez and M. Bardi, Singular perturbations of nonlinear degenerate parabolic PDEs: a general convergence result, *Arch. Ration. Mech. Analysis* 170 (2003), 17–61.
- [A-B-M] O. Alvarez, M. Bardi and C. Marchi, Multiscale problems and homogenization of second-order Hamilton-Jacobi equations, preprint.
- [A-F] L. Ambrosio and H. Frid, Multiscale Young measures in almost periodic homogenization and applications, preprint.
- [A-R-T] P. Auscher, E. Russ, Emmanuel and P. Tchamitchian, Une note sur les lemmes div-curl, *C. R. Math. Acad. Sci. Paris* 337 (2003), 511–516.

- [B-R-T] P. Bagnerini, M. Rascle and E. Tadmor, Compensated compactness for 2D conservation laws, *J. Hyperbolic Differ. Equ.* 2 (2005), 697–712.
- [Be] F. Bethuel, On the singular set of stationary harmonic maps, *Manuscripta Math.* 78 (1993), 417–443.
- [B-B1] J. Bourgain and H. Brezis, On the equation  $\operatorname{div} Y = f$  and application to control of phases, *J. Amer. Math. Soc.* 16 (2003), 393–426
- [B-B2] J. Bourgain and H. Brezis, New estimates for the Laplacian, the div-curl, and related Hodge systems, *C. R. Math. Acad. Sci. Paris* 338 (2004), 539–543.
- [B-D] A. Braides and A. Defranceschi, *Homogenization of Multiple Integrals*, Oxford University Press, 1998.
- [B-CD] M. Briane and J. Casado-Daz, Lack of compactness in two-scale convergence, *SIAM J. Math. Analysis* 37 (2005), 343–346.
- [Cp] Y. Capdeboscq, Homogenization of a diffusion equation with drift. *C. R. Acad. Sci. Paris Sr. I Math.* 327 (1998), 807–812.
- [Ch] G.-Q. Chen, Compactness methods and nonlinear hyperbolic conservation laws, in *Some Current Topics on Nonlinear Conservation Laws*, 33–75, AMS/IP Stud. Adv. Math., 15, Amer. Math. Soc, 2000.
- [C-D-S-W] G.-Q. Chen, C. Dafermos, M. Slemrod and D. Wang, On two dimensional sonic-subsonic flow, preprint, 2006.
- [C-J-R] G.-Q. Chen, S. Junca and M. Rascle, Validity of nonlinear geometric optics for entropy solutions of multidimensional scalar conservation laws, *J. Differential Equations* 222 (2006), 439–475.
- [C-LF] G.-Q. Chen and P. LeFloch, Existence theory for the isentropic Euler equations, *Arch. Ration. Mech. Analysis* 166 (2003), 81–98.
- [C-K] A. Cherkaev and R. Kohn, editors, *Topics in the Mathematical Modelling of Composite Materials*, Birkhäuser, 1997.
- [C-W-Y] S-Y Chang, L. Wang and P. Yang, A regularity theory of biharmonic maps, *Comm. Pure Appl. Math.* 52 (1999), 1113–1137
- [C-D-DA] D. Cioranescu, A. Damlamian and R. De Arcangelis, Homogenization of non-linear integrals via the periodic unfolding method, *C. R. Math. Acad. Sci. Paris* 339 (2004), 77–82.

- [C-D-G] D. Cioranescu, A. Damlamian and G. Griso, Periodic unfolding and homogenization, *C. R. Math. Acad. Sci. Paris* 335 (2002), 99–104.
- [C-L-M-S] R. Coifman, P. L. Lions, Y. Meyer and S. Semmes, Compensated compactness and Hardy spaces, *J. Math. Pures Appl.* 72 (1993), 247–286.
- [C-M] R. Coifman and Y. Meyer, On commutators of singular integrals and bilinear singular integrals, *Trans. Amer. Math. Soc.* 212 (1975), 315–331.
- [D] C. Dafermos, *Hyperbolic Conservation Laws in Continuum Physics*, second edition, Springer, 2005.
- [Dl] J.-M. Delort, Existence de nappes de tourbillon pour l’équation d’Euler sur le plan, *Seminaire sur les equations aux Derivees Partielles*, 1990–1991, Exp. No. II, Ecole Polytech., Palaiseau, 1991.
- [D-K-M-O] A. DeSimone, R. Kohn, S. Müller and F. Otto, A compactness result in the gradient theory of phase transitions, *Proc. Roy. Soc. Edinburgh Sect. A* 131 (2001), 833–844.
- [E5] L. C. Evans, Partial regularity for stationary harmonic maps into spheres, *Arch. Rational Mech. Analysis* 116 (1991), 101–113.
- [E-M] L. C. Evans and S. Müller, Hardy spaces and the two-dimensional Euler equations with nonnegative vorticity, *J. Amer. Math. Soc.* 7 (1994), 199–219.
- [E-P] L. C. Evans and M. Portilheiro, Irreversibility and hysteresis for a forward-backward diffusion equation. *Math. Models Methods Appl. Sci.* 14 (2004), 1599–1620.
- [Fe] E. Feireisl, *Dynamics of Viscous Compressible Fluids*, Oxford Lecture Series in Mathematics and its Applications, 26, Oxford University Press, 2004.
- [F-J-M1] G. Friesecke, R. James and S. Muller, A theorem on geometric rigidity and the derivation of nonlinear plate theory from three-dimensional elasticity, *Comm. Pure Appl. Math.* 55 (2002), 1461–1506.
- [F-J-M2] G. Friesecke, R. James and S. Muller, A hierarchy of plate models derived from nonlinear elasticity by gamma-convergence, *Arch. Ration. Mech. Analysis* 180 (2006), 183–236.
- [G-L] F. Golse and D. Levermore, Hydrodynamic limits of kinetic models, *Fields Institute Communications* 46 (2005), 1–75.

- [H] F. Helein, *Harmonic Maps, Conservation Laws and Moving Frames*, Second edition. Cambridge Tracts in Mathematics, 150. Cambridge University Press, 2002.
- [I] T. Iwaniec,  $p$ -harmonic tensors and quasiregular mappings, *Ann. of Math. (2)* 136 (1992), 589–624.
- [I-M1] T. Iwaniec and G. Martin, Quasiregular mappings in even dimensions, *Acta Math.* 170 (1993), 29–81.
- [I-M2] T. Iwaniec and G. Martin, *Geometric Function Theory and Nonlinear Analysis*, Oxford University Press, 2001.
- [J-P] P-E, Jabin and B. Perthame, Compactness in Ginzburg-Landau energy by kinetic averaging, *Comm. Pure Appl. Math.* 54 (2001), 1096–1109.
- [K-T] M. Katsoulakis and A. Tzavaras, Contractive relaxation systems and the scalar multidimensional conservation law, *Comm. Partial Differential Equations* 22 (1997), 195–233.
- [K-M1] S. Klainerman and M. Machedon, Space-time estimates for null forms and the local existence theorem, *Comm. Pure Appl. Math.* 46 (1993), 1221–1268.
- [K-M2] S. Klainerman and M. Machedon, Smoothing estimates for null forms and applications, *Duke Math. J.* 81 (1995), 99–133.
- [K-M3] S. Klainerman and M. Machedon, Estimates for null forms and the spaces  $H_{s,\delta}$ , *Internat. Math. Res. Notices* 17 (1996) 853–865.
- [L1] P. L. Lions, *Mathematical Topics in Fluid Mechanics, Volume I: Incompressible Models*, Oxford University Press, 1996.
- [L2] P. L. Lions, *Mathematical Topics in Fluid Mechanics, Volume II: Compressible Models*, Oxford University Press, 1998.
- [L-N-W] D. Lukkassen, G. Nguetseng and P. Wall, Two-scale convergence, *Int. J. Pure Appl. Math.* 2 (2002), 35–86.
- [Mc] M. Machedon, Fourier analysis of null forms and non-linear wave equations, *Proceedings of the International Congress of Mathematicians, Vol. III (Berlin, 1998)*. *Doc. Math.* 1998, Extra Vol. III, 49–55.
- [Mo] C. Morawetz, An alternative proof of DiPerna’s theorem, *Comm. Pure Appl. Math.* 44 (1991), 1081–1090

- [M-S2] S. Müller and V. Sverak, On surfaces of finite total curvature, *J. Differential Geom.* 42 (1995), 229–258.
- [Ng] G. Nguetseng, A general convergence result for a functional related to the theory of homogenization, *SIAM J. Math. Anal.* 20 (1989), 608–623.
- [Pl] P. I. Plotnikov, Equations with a variable direction of parabolicity and the hysteresis effect. (Russian) *Dokl. Akad. Nauk* 330 (1993), 691–693; translation in *Russian Acad. Sci. Dokl. Math.* 47 (1993), 604–608.
- [Po1] M. Portilheiro, Weak solutions for equations defined by accretive operators I, *Proc. Roy. Soc. Edinburgh Sect. A* 133 (2003), 1193–1207.
- [Po2] M. Portilheiro, Weak solutions for equations defined by accretive operators II, relaxation limits, *J. Differential Equations* 195 (2003), 66–81.
- [Rv1] T. Riviere, Conservation laws for conformal invariant variational problems, preprint, 2006.
- [Rv-S] T. Riviere and M. Struwe, Partial regularity for harmonic maps and related problems, preprint, 2006.
- [S] S. Semmes, A primer on Hardy spaces and some remarks on a theorem of Evans and Müller, *Comm. Partial Differential Equations* 19 (1994) 277–319.
- [S-S] J. Shatah and M. Struwe, *Geometric Wave Equations*, Courant Lecture Notes in Mathematics, 2, American Mathematical Society, 1998.
- [Sg] C. Sogge, *Lectures on Nonlinear Wave Equations*, Monographs in Analysis, II. International Press, 1995.
- [St] E. Stein, *Harmonic Analysis: Real-Variable Methods, Orthogonality, and Oscillatory Integrals*, with the assistance of T. Murphy, Princeton Mathematical Series, 43, Princeton University Press, 1993.
- [Sz] P. Strzelecki, A new proof of regularity of weak solutions of the  $H$ -surface equation, *Calc. Var. Partial Differential Equations* 16 (2003), 227–242.
- [Tz] A. Tzavaras, The Riemann function, singular entropies and the structure of oscillations in systems of two conservation laws, *Arch. Ration. Mech. Analysis* 169 (2003), 119–145.
- [VS] J. Van Schaftingen, Estimates for  $L^1$ -vector fields, *C. R. Math. Acad. Sci. Paris* 339 (2004), 181–186.



## CONCENTRATION

- [B-G] H. Bahouri and P. Gerard, High frequency approximation of solutions to critical nonlinear wave equations, *Amer. J. Math.* 121 (1999), 131–175.
- [B-B-H] F. Bethuel, H. Brezis and F. Helein, *Ginzburg-Landau Vortices*, Birkhäuser, 1994.
- [B-O-S1] F. Bethuel, G. Orlandi, and D. Smets, Quantization and motion law for Ginzburg-Landau vortices, preprint.
- [B-O-S2] F. Bethuel, G. Orlandi, and D. Smets, Convergence of the parabolic Ginzburg-Landau equation to motion by mean curvature. *Ann. of Math.* 163 (2006), 37–163.
- [B-O-S3] F. Bethuel, G. Orlandi, and D. Smets, Motion of concentration sets in Ginzburg-Landau equations, *Ann. Fac. Sci. Toulouse Math.* (6) 13 (2004), 3–43.
- [B-C-L] H. Brezis, J-M. Coron and E. Lieb, Harmonic maps with defects, *Comm. Math. Phys.* 107 (1986), 649–705.
- [B-J] J. C. Bronski and R. Jerrard, Soliton dynamics in a potential, *Math. Res. Lett.* 7 (2000), 329–342
- [Bq] N. Burq, Mesures semi-classiques et mesures de défaut, *Seminaire Bourbaki*, Vol. 1996/97, Asterisque No. 245 (1997), Exp. No. 826, 167–195.
- [D-L1] R. DiPerna and P.-L. Lions, On the Cauchy problem for Boltzmann equations: global existence and weak stability, *Ann. of Math.* 130 (1989), 321–366.
- [D-L2] R. DiPerna and P.-L. Lions, Global solutions of Boltzmann’s equation and the entropy inequality, *Arch. Rational Mech. Analysis* 114 (1991), 47–55.
- [D-H] O. Druet and E. Hebey, Elliptic equations of Yamabe type, *IMRS Int. Math. Res. Surveys* 2005, 1–113.
- [E-Z] L. C. Evans and M. Zworski, *Lectures on Semiclassical Analysis*, extremely preliminary version. Download: [math.berkeley.edu/~evans/semiclassical.pdf](http://math.berkeley.edu/~evans/semiclassical.pdf)
- [Fr] G. Francfort, An introduction to H-measures and their applications, 85–110, in *Variational Problems in Materials Science*, ed. by G. dal Maso, A. DeSimone and F. Tomarelli, Birkhäuser, 2006.

- [F-M] G. Francfort and F. Murat, Oscillations and energy densities in the wave equation, *Comm. Partial Differential Equations* 17 (1992), 1785–1865.
- [G1] P. Gerard, Microlocal defect measures, *Comm. Partial Differential Equations* 16 (1991), 1761–1794.
- [G2] P. Gerard, Oscillations and concentration effects in semilinear dispersive wave equations, *J. Funct. Analysis* 141 (1996), 60–98.
- [G-M-M-P] P. Gerard, P. Markowich, N. Mauser and F. Poupaud, Homogenization limits and Wigner transforms, *Comm. Pure Appl. Math.* 50 (1997), 323–379. Erratum: *Comm. Pure Appl. Math.* 53 (2000), 280–281.
- [G-SR] F. Golse and L. Saint-Raymond, The Navier-Stokes limit of the Boltzmann equation for bounded collision kernels, *Invent. Math.* 155 (2004), 81–161.
- [Gr] M. Grillakis, Regularity and asymptotic behaviour of the wave equation with a critical nonlinearity, *Ann. of Math* 132 (1990), 485–509.
- [J-S1] R. Jerrard and M. Soner, The Jacobian and the Ginzburg-Landau energy, *Calc. Var. Partial Differential Equations* 14 (2002), 151–191.
- [J-S2] R. Jerrard and M. Soner, Dynamics of Ginzburg-Landau vortices, *Arch. Rational Mech. Analysis* 142 (1998), 99–125.
- [J-M-R] J.-L. Joly, G. Metivier and J. Rauch, Trilinear compensated compactness and nonlinear geometric optics, *Ann. of Math.* 142 (1995), 121–169.
- [Kr] S. Keraani, Limite semi-classique pour l'équation de Schrödinger non-linéaire avec potentiel harmonique, *C. R. Math. Acad. Sci. Paris* 340 (2005) 809–814.
- [L-T] J. Li and G. Tian, A blow-up formula for stationary harmonic maps. *Internat. Math. Res. Notices* 1998, 735–755.
- [L-Z1] Y-Y Li and L. Zhang, Compactness of solutions to the Yamabe problem, *C. R. Math. Acad. Sci. Paris* 338 (2004), 693–695.
- [L-Z2] Y-Y Li and L. Zhang, Compactness of solutions to the Yamabe problem, II. *Calc. Var. Partial Differential Equations* 24 (2005), 185–237.
- [Ln1] F.-H. Lin, Gradient estimates and blow-up analysis for stationary harmonic maps. *Ann. of Math.* 149 (1999), no. 3, 785–829.

- [Ln2] F.-H. Lin, Rectifiability of defect measures, fundamental groups and density of Sobolev mappings, Journes “Equations aux Derivees Partielles” (Saint-Jean-de-Monts, 1996), Exp. No. XII, 14 pp., Ecole Polytech., 1996.
- [L-W1] F.-H. Lin and C. Wang, Harmonic and quasi-harmonic spheres, *Comm. Anal. Geom.* 7 (1999), 397–429.
- [L-W2] F.-H. Lin and C. Wang, Harmonic and quasi-harmonic spheres. II. *Comm. Anal. Geom.* 10 (2002), 341–375.
- [L-W3] F.-H. Lin and C. Wang, Harmonic and quasi-harmonic spheres. III. Rectifiability of the parabolic defect measure and generalized varifold flows. *Ann. Inst. H. Poincaré Anal. Non Linéaire* 19 (2002), 209–259.
- [L3] P.-L. Lions, Renormalized solutions of some transport equations with partially  $W^{1,1}$  velocities and applications, *Ann. Mat. Pura Appl.* 183 (2004), 97–130.
- [L-P] P.-L. Lions and T. Paul, Sur les mesures de Wigner, *Wigner Rev. Mat. Iberoamericana* 9 (1993), 553–618.
- [M] R. Moser, Stationary measures and rectifiability, *Calc. Var. Partial Differential Equations* 17 (2003), 357–368.
- [P-R] F. Pacard and T. Riviere, *Linear and Nonlinear Aspects of Vortices. The Ginzburg-Landau Model*, Progress in Nonlinear Differential Equations and their Applications, 39. Birkhäuser, 2000.
- [Pd] P. Pedregal, *Parametrized Measures and Variational Principles*, Progress in Nonlinear Differential Equations and their Applications 30, Birkhäuser, 1997.
- [Rv2] T. Riviere, Line vortices in the  $U(1)$ -Higgs model, *ESAIM COCV* 1 (1995/96), 77–167.
- [Sr] S. Serfaty, Gamma-convergence of gradient flows with applications to Ginzburg-Landau, *Comm. Pure Appl. Math.* 57 (2004), 1627–1672.
- [S-S] J. Shatah and M. Struwe, *Geometric Wave Equations*, Courant Lecture Notes in Mathematics 2, American Mathematical Society, 1998.
- [T1] L. Tartar, *Homogenization, Compensated Compactness and H-Measures*, lecture notes for CBMS conference, UC Santa Cruz, 1993.
- [T2] L. Tartar,  $H$ -measures, a new approach for studying homogenisation, oscillations and concentration effects in partial differential equations. *Proc. Roy. Soc. Edinburgh Sect. A* 115 (1990), 193–230.

- [T3] L. Tartar, On mathematical tools for studying partial differential equations of continuum physics:  $H$ -measures and Young measures, in *Developments in Partial Differential Equations and Applications to Mathematical Physics*, 201–217, Plenum, 1992.
- [Z-Z1] P. Zhang and Y. Zheng, Weak solutions to a nonlinear variational wave equation, *Arch. Ration. Mech. Analysis* 166 (2003), 303–319.
- [Z-Z2] P. Zhang and Y. Zheng, Weak solutions to a nonlinear variational wave equation with general data, *Ann. Inst. H. Poincaré Analyse Non Linéaire* 22 (2005), 207–226.

### OTHER METHODS

- [B-CD] M. Bardi and I. Capuzzo-Dolcetta, *Optimal Control and Viscosity Solutions of Hamilton-Jacobi-Bellman Equations*, with appendices by Maurizio Falcone and Pierpaolo Soravia, Birkhäuser, 1997.
- [B-G-P] F. Bouchut, F. Golse and M. Pulvirenti, *Kinetic Equations and Asymptotic Theory*, edited by B. Perthame and L. Desvillettes, Gauthier-Villars, Elsevier, 2000.
- [Br] A. Braides,  *$\Gamma$ -Convergence for Beginners*, Oxford Lecture Series in Mathematics and its Applications, 22, Oxford University Press, 2002.
- [DM] G. Dal Maso, *An Introduction to  $\Gamma$ -Convergence*, Progress in Nonlinear Differential Equations and their Applications 8, Birkhäuser, 1993.
- [P1] B. Perthame, *Kinetic Formulation of Conservation Laws*, Oxford Lecture Series in Mathematics and its Applications, 21, Oxford University Press, 2002.