

ON NUMBER THEORETIC PROPERTIES OF THE KDV FREQUENCIES

THOMAS KAPPELER AND JÜRG KRAMER*

Abstract. In this paper we investigate some number theoretic properties of the frequencies of the Korteweg-de Vries equation on the torus, relevant for the stability of finite gap solutions.

Mathematics subject classification (2020): 37K10, 35Q53, 37K45, 11D25, 11D41, 11G30, 14G05.

Keywords and phrases: KdV equation, finite gap solutions, stability, Hamiltonian perturbations, resonances, arithmetic algebraic geometry, diophantine equations, rational points.

REFERENCES

- [1] P. BALDI, M. BERTI, R. MONTALTO, *KAM for autonomous quasi-linear perturbations of KdV*, Ann. Inst. H. Poincaré Analyse Non Linéaire, **33** (2016), no. 6, 1589–1638.
- [2] D. BAMBUSI, *Nekhoroshev theorem for small amplitude solutions in nonlinear Schrödinger equations*, Math. Z. **130** (1999), 345–387.
- [3] D. BAMBUSI, *Birkhoff normal form for some nonlinear PDEs*, Math. Phys. **234** (2003), no. 2, 253–285.
- [4] D. BAMBUSI, B. GRÉBERT, *Birkhoff normal form for partial differential equations with tame modulus*, Duke Math. J. **135** (2006), no. 3, 507–567.
- [5] J. BERNIER, E. FAOU, G. GRÉBERT, *Rational normal forms and stability of small solutions to nonlinear Schrödinger equations*, arXiv:1812.11414, 2020.
- [6] J. BERNIER, B. GRÉBERT, *Long time dynamics for generalized Korteweg-de Vries and Benjamin-Ono equations*, Arch. Ration. Mech. Anal. **241** (2021), no. 3, 1139–1241.
- [7] M. BERTI, J. DELORT, *Almost global solutions of capillary-gravity water waves equations on the circle*, Lecture Notes of the Unione Matematica Italiana, **24**, Springer, 2018.
- [8] M. BERTI, T. KAPPELER, R. MONTALTO, *Large KAM tori for quasi-linear perturbations of KdV*, Arch. Ration. Mech. Anal. **239** (2021), 1395–1500.
- [9] R. BIKBAEV, S. KUKSIN, *On the parametrization of finite-gap solutions by frequency vector and wave number vectors and a theorem by I. Krichever*, Lett. Math. Phys. **28** (1993), 115–122.
- [10] J. BOURGAIN, *Quasi-periodic solutions of Hamiltonian perturbations of 2D linear Schrödinger equations*, Ann. of Math. **148** (1998), 363–439.
- [11] J. BOURGAIN, *On diffusion in high dimensional Hamiltonian systems and PDE*, J. Anal. Math. **80** (2000), 1–35.
- [12] J. BOUSSINESQ, *Théorie de l'intumescence liquid appelée onde solitaire ou de translation, se propageant dans un canal rectangulaire*, Comptes Rend. Acad. Sci. (Paris) **72** (1871), 755–759.
- [13] H. CONG, J. LIU, Y. SHI, X. YUAN, *The stability of full dimensional KAM tori for nonlinear Schrödinger equation*, J. Differential Equations **264** (2018), no. 7, 4504–4563.
- [14] J.-M. DELORT, *A quasi-linear Birkhoff normal forms method. Application to the quasi-linear Klein-Gordon equation on S^1* , Astérisque no. **341** (2012).
- [15] DISPERSIVE WIKI, <http://wiki.math.toronto.edu/DispersiveWiki/>.
- [16] I. V. DOLGACHEV, *Classical Algebraic Geometry*, Cambridge University Press, Cambridge 2012.
- [17] B. DUBROVIN, I. KRICHEVER, S. NOVIKOV, *Integrable systems I in Dynamical Systems IV*, Encyclopedia of Mathematical Sciences vol. 4, V. Arnold, S. Novikov (eds.), 173–280, Springer, 1990.
- [18] N. ELKIES, *Complete cubic parametrization of the Fermat cubic surface*, <https://people.math.harvard.edu/~elkies/4cubes.html>.
- [19] L. EULER, *Elements of algebra*, 3rd ed., Longmans, London, 1822.

- [20] L. FADDEV, L. TAKHTAJAN, *Hamiltonian methods in the theory of solitons*, Springer, 1987.
- [21] G. FALTINGS, *Endlichkeitssätze für abelsche Varietäten*, Invent. Math. **73** (1983), 349–366.
- [22] R. FEOLA, F. IANDOLI, *A non-linear Egorov theorem and Poincaré-Birkhoff normal forms for quasi-linear pdes on the circle*, arXiv:2002.12448, 2020.
- [23] C. GARDNER, J. GREENE, M. KRUSKAL, R. MIURA, *Korteweg-de Vries equation and generalizations. VI. Methods for exact solution*, Comm. Pure Appl. Math. **27** (1974), 97–133.
- [24] H. GUAN, S. KUJSIN, *The KdV equation under periodic boundary conditions and its perturbations*, Nonlinearity **27** (2014), no. 9, R61–R88.
- [25] T. KAPPELER, R. MONTALTO, *Normal form coordinates for the KdV equation having expansions in terms of pseudodifferential operators*, Comm. Math. Phys. **375** (2020), no. 1, 833–913.
- [26] T. KAPPELER, R. MONTALTO, *Stability results for periodic multi-solitons of the KdV equation*, Comm. Math. Phys. **385** (2021), no. 3, 1871–1956.
- [27] T. KAPPELER, J. PÖSCHEL, *KdV & KAM*, Springer-Verlag, 2003.
- [28] T. KAPPELER, B. SCHAAD, P. TOPALOV, *Asymptotics of spectral quantities of Schrödinger operators*, Spectral geometry, 243–284, Proc. Sympos. Pure Math., **84**, Amer. Math. Soc., Providence, RI, 2012.
- [29] D. KORTEWEG, G. DE VRIES, *On the change of form of long waves advancing in rectangular canal, and on a new type of long stationary waves*, Phil. Mag. Ser. 5, **39** (1895), 422–443.
- [30] J. KRAMER, A.-M. VON PIPPICH, *From Natural Numbers to Quaternions*, Springer Undergraduate Mathematics Series, Springer International Publishing, 2017.
- [31] M. KRUSKAL, N. ZABUSKY, *Interactions of ‘solitons’ in a collisionless plasma and the recurrence of initial states*, Phys. Rev. Lett. **15** (1965), 240–243.
- [32] S. KUJSIN, *Hamiltonian perturbations of infinite-dimensional linear systems with an imaginary spectrum*, Funct. Anal. Appl. **21** (1987), 192–205.
- [33] S. KUJSIN, *A KAM theorem for equations of the Korteweg-de Vries type*, Rev. Math. Phys. **10** (1998), no. 3, 1–64.
- [34] S. KUJSIN, *Analysis of Hamiltonian PDEs*, Oxford University Press, 2000.
- [35] P. LAX, *Integrals of nonlinear equations of evolution and solitary waves*, Comm. Pure Appl. Math. **21** (1968), 468–490.
- [36] R. MIURA, C. GARDNER, M. KRUSKAL, *Korteweg-de Vries equation and generalizations. II. Existence of conservation laws and constants of motion*, J. Math. Physics **9** (1968), 1204–1209.
- [37] J. PÖSCHEL, E. TRUBOWITZ, *Inverse spectral theory*, Academic Press, 1987.
- [38] LORD RAYLEIGH, *On waves*, In: *Report of the fourteenth Meeting of the British Association for the Association for the Advancement of Sciences*, John Murray, London 1844, 311–390.
- [39] E. WAYNE, *Periodic and quasi-periodic solutions of nonlinear wave equations via KAM theory*, Comm. Math. Phys. **127** (1990), no. 3, 479–528.