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Victor J. Emery and recent applications of his ideas

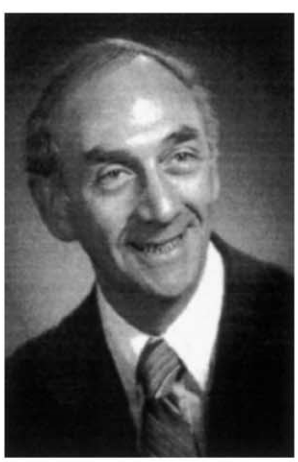
Serguei Brazovskii [a,b] *

[a] LPTMS, Bât. 100, Université Paris-Sud, 91405 Orsay, Cedex, France
[b] Landau Institute, Moscow, Russia

Abstract

Victor Emery made seminal contributions to the theory of one-dimensional electronic systems and to its applications to organic metals. His inventions became illuminated recently when the joint effect of the ferroelectricity and the charge disproportionation has been discovered in $(TMTTF)_2X$ compounds and beyond. Several of his contributions came to agenda at once: separate gaps in spin/charge channels and the route to solitons, $4k_F$ anomaly, dimerization gap, role of ionic transitions. New phenomena unify an unusual variety of concepts: ferroelectricity of good conductors, structural instability towards Mott-Hubbard state, Wigner crystallization in a dense electronic system, ordered $4k_F$ density wave, richness of physics of solitons, interplay of structural and electronic symmetries. The ferroelectric state gives rise to several types of solitons carrying the electron charge, a noninteger charge, spin or both the spin and the charge in special cases. They are clearly observed via conductivity, electric and magnetic susceptibilities. Solitons are challenging for optics where they already seem to determine the pseudogap in absorption. Various features also appear, or are expected, from collective electronic and coupled electron-phonon modes. The last topic, as well as some aspects of physics of solitons, recalls also the contributions of M.J. Rice. Moreover, the observation of Mott-Hubbard states refers to classical results of A.A. Ovchinnikov.

Keywords: One-dimensional systems, interacting electrons, ferroelectricity, charge disproportionation, solitons, CDW, Wigner crystal.



Victor John Emery: 16 May 1934 – 17 July 2002

"His experiences with an early digital computer likely persuaded him of the value of more analytical approaches." – *from memoirs about Victor Emery.*

Victor Emery lived as an extraordinary strong personality: humanly, intellectually, physically, and psychologically. He died at the (ever-lasting) summit of accomplishments, withstanding courageously a devastating illness.

A lone ranger of the APS landscape, Vic Emery got a surprisingly late formal recognition in the US: the fellow of the American Academy of Arts & Sciences in 2000 and the Oliver E. Buckley Prize in 2001 (with Alan Luther). However, his true authority in science is imprinted in models and solutions bearing his name, in vast citations of his articles and in even wider inspirations among experimentalists and theorists.

For us, Victor Emery is a man of epochs of Organic Metals and of High-Tc superconductors; one of those who made the epochs. Vic Emery came to the science of low dimensional electronic systems both as a curious researcher and as a leading theorist of the exceptional group of Brookhaven National Laboratory. The BNL responsibility, lasting for nearly four decades, was his overwhelming duty, until the very last days of his life. Vic was always close to the neutron scattering experiments at BNL. Thus, together with J. Axe, he has developed a theory of the structure factor for 1D crystals in connection to experiments on the "alchemist gold" $Hg_{3-x}AsF_6$ [1] which was showing an intriguing crystalline pseudo long-range order of mercury chains (*cf.* J.-P. Pouget et al at the BNL). For organic metals, Emery (*together with Per Bak: a sad occasion to commemorate another renowned scientist recently passed away*) has proposed a phenomenological theory [2] devoted to the rich phase

*Corresponding author: E-mail; brazov@ipno.in2p3.fr

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diagram of the TTF-TCNQ compound. The theory has revealed an unusual interplay of incommensurate structures (cf. R.Comes and G.Shirane, BNL-Orsay) as well as conductance anomalies. The TTF-TCNQ compound was the primary object of worship, in these early days of Synthetic Metals, and still is on agenda today, *cf.* S.Ravy et al.

The most striking feature of the TTF-TCNQ was the so-called $4K_F$ Charge Density Wave - CDW (*cf.* J.P. Pouget et al. in Orsay and also S. Kagoshima in Tokyo) in which the wave number, "$4K_F$", corresponds to one electron per CDW period in comparison with two electrons for conventional, i.e. $2K_F$, CDWs. The theory of Emery [3] assigns an organic metal showing the $4K_F$ anomaly to a detached region of the electronic phase diagram, which is essentially characteristic of strongly correlated systems. Today, we also interpret the $4K_F$ anomaly as the formation of a 1D Wigner crystal thus even building a bridge to semiconducting nano-wires. Recently, the hidden condensation of a commensurate $4K_F$ CDW was identified (*cf.* P.Monceau, F.Nad, S.B., and S.Brown et al) via the new effects of the charge disproportionation and ferroelectricity, which we shall address separately.

A fundamental contribution of that time, also most relevant today, was the work of V.Emery together with A.Luther [4] which results are imprinted in theorists' language as the "Luther-Emery line" and the "Luther-Emery liquid". This work has given a clear view on the spin-charge separation with the direct access to exotic elementary excitations: spinons or holons, described as Sin-Gordon solitons; their classical version was baptized as "φ-particles" by M.J.Rice et al.

Since the discovery (*cf.* D.Jerome et al, Orsay, 1980) of the first organic superconductors, the Bechgaard-Fabre salts $(TMTCF)_2X$, Vic Emery stayed close both to fundamental issues of the theory and to all details on new materials. Thus, he was the first [5] (in parallel to our work with S.Barisic) to pay attention to the effect of a weak dimerization of bonds in $(TMTCF)_2X$ as a drive towards the Mott insulator state. (Here his early work with A.Luther has found the direct application.)

Vic Emery kept being very attentive to new data appearing in the world, sometimes more than people at laboratories of original experiments did. Thus, he realized the importance of tiny structural changes due to subtle transitions of "anionic ordering" AO [5]. (A full rich picture of AOs was published only in 1996, in a review by J.-P.Pouget and S.Ravy written for a memorial volume (*edited by the present author*) of Igor Schegolev, one of patriarchs of Synthetic Metals. Vic Emery offered a statistical model to unify the diversity of structures [6]. He also speculated [7] on a relation between the specific anionic transition in $(TMTSF)_2ClO_4$ and the superconductivity observed in this compound. This question came to agenda recently once again: as a hysteresis at the SDW/SC boundary between the Spin Density Wave and the Superconductivity (*cf.* P.Chaikin et al, D.Jerome et al).

By the mid 80's Vic Emery turned his interests to topics of the Kondo effect, his old passions, where he and co-workers found e.g. solutions for the 1D Kondo lattice.

When the High-Tc epoch broke out, BNL became one of the world leading centers. For Vic Emery that was a time of restless activity, both in his own theoretical work and concerning the impact of his leadership at the BNL and beyond. The first accomplishment of Vic Emery was to suggest a model [8], bearing his name ever since. It describes the CuO_2 plane as a system combining features of both the charge transfer and correlation gaps with conducting holes moving over the oxygen network.

The latest passion of Vic Emery became the physics of stripes discovered and studied (*cf.* J.Tranquada et al) at BNL; Vic Emery explored this field with a remarkable activity until his last days. The extravagant view of V.Emery and his co-authors was that stripes might favor the superconductivity, and even bring it to existence in cuprates.

The BNL Bulletin, *v.56, No.27, 9 August 2002*, see also *J.Tranquada et al, Physics Today, v.57, No. 10, p. 92 (2004)*, reviews these last parts of scientific accomplishments of Victor Emery in more details.

Unwanted thoughts. Dream of integrity.

It is an accident, a very sad one that several prominent contributors, each of them in full intellectual power, have passed away in a short time between the two ICSMs. It could be only a coincidence that all of them were theorists. However, there is something special behind the willing of our community to hold a memorial session devoted to them.

After decades of intense academic activity, Synthetic Metals have reached the focus of material engineering, with wide applications and even commercialization. So it is not quite surprising that the healthy and wealthy pi-conjugated children (polymers, fullerenes, nano-tubes) dominate over their more academic older brothers (CDWs have been pushed away from the cuckoo nest long time ago; organic metals are left for mercy, but the two communities are transparent as reciprocally dark matters, or as participants of parallel sessions at the ICSMs). In theory of conducting polymers and around, analytic approaches have largely been replaced by numerical experiments, usually with a lower accuracy than the real ones. This tendency starts to show up in organic metals as well, while here there are helpful studies on the borderline of analytics and numerics.

Nevertheless, the demonstrated respect to the heritance of prominent theorist uncovers a deep feeling of fundamental grounds of our science and a hidden faith in its integrity. The curious history presented below demonstrates the merits of integrity in an amusing efficiency.

Only the exchange of methods and concepts among CDWs, Organic Metals and Conducting Polymers allowed to resolve the two decades lasting mystery and to turn around a seemingly well-established picture.

Turmoil of 2000's: ferroelectricity and charge disproportionation in organic conductors.

Plenty of experiments were performed and many theoretical speculations were proposed already within the

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