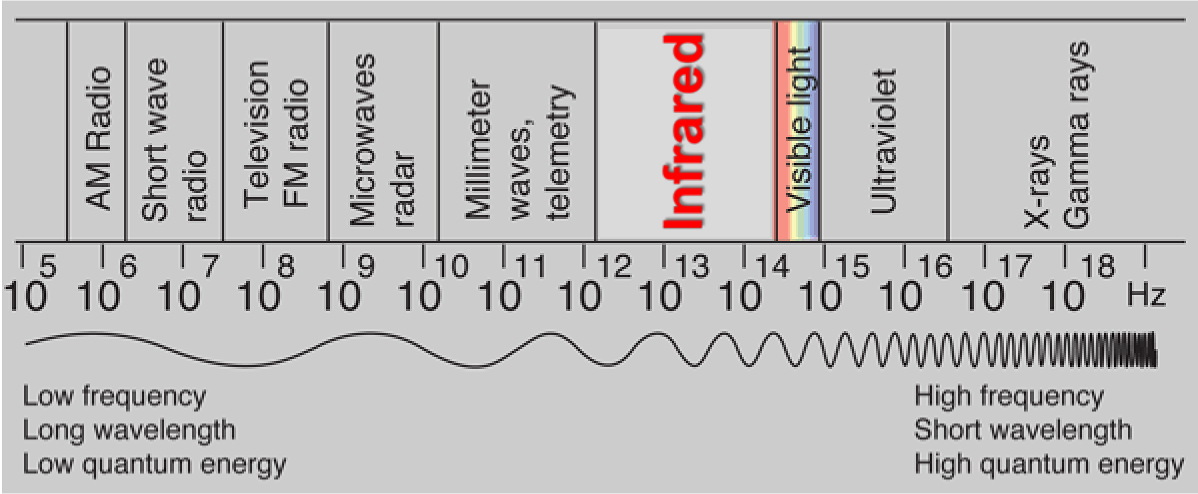
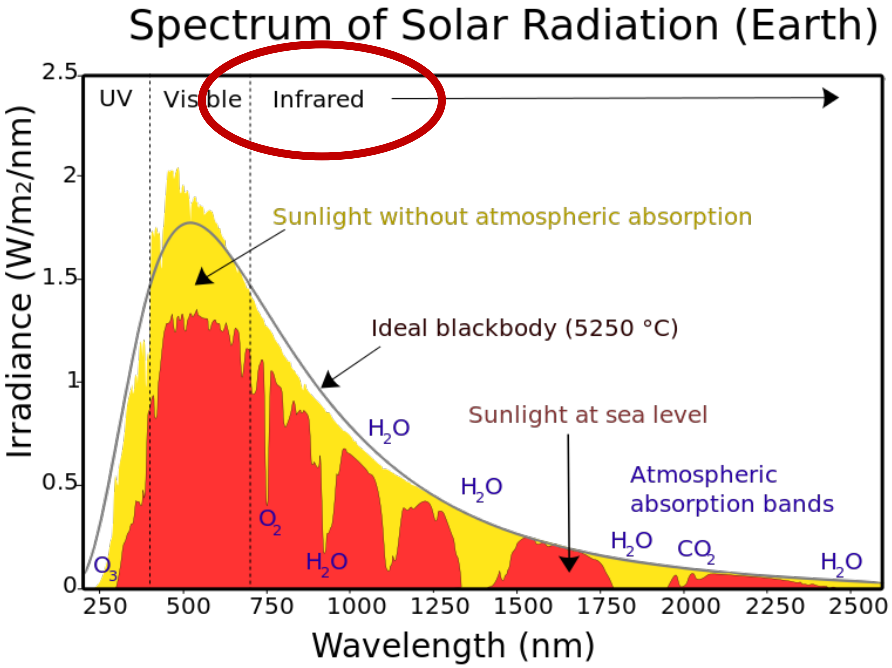
Infrared radiation

Thermoelectricity

Chaos

Infrared radiation





Use natural sources of infrared radiation ......

← **Solar spectrum**

Fire →

Black-body radiation

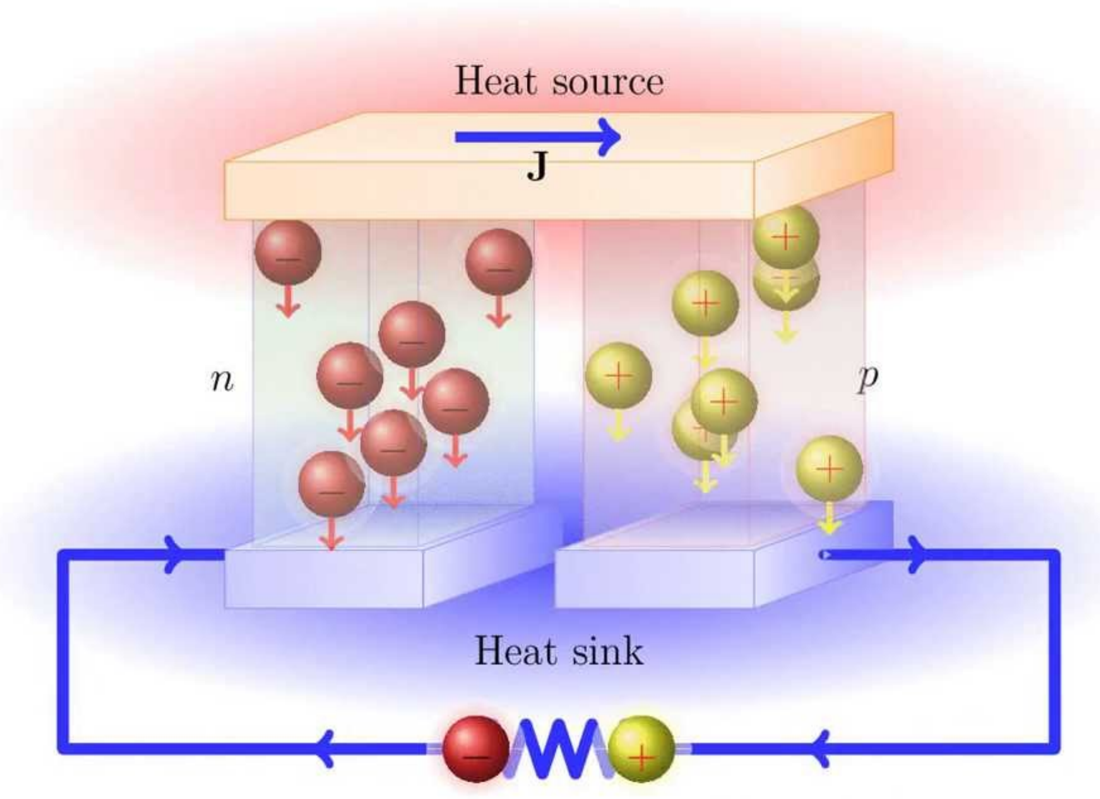
Infrared radiation

… and transform the radiation into usable energy…

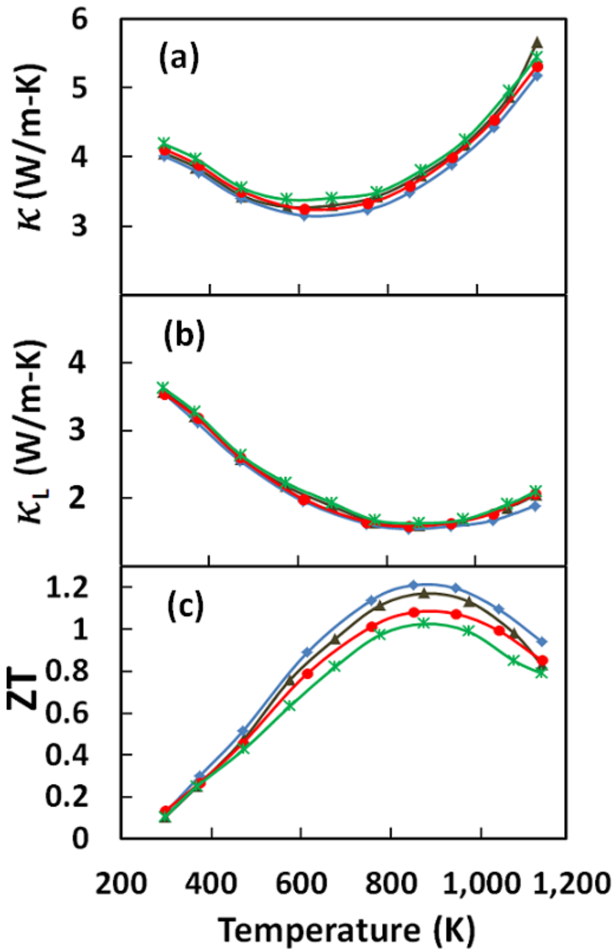
…available **day** and **night!**

Thermoelectricity

Seebeck effect



Thermoelectricity



(Submitted for publication, May 28 2015)

Uncovering High Thermoelectric Figure of Merit in (Hf,Zr)NiSn Half-Heusler Alloys

L. Chen,[1] S. Gao,[1] X. Zeng,[2] A. M. Dehkordi,[3] T. M Tritt,[2,3] and **S. J. Poon**[1,a]

[1] *Department of Physics, University of Virginia, Charlottesville, Virginia 22904-4714*

[2] *Department of Physics and Astronomy, Clemson University, Clemson, South Carolina 29634-0978*

[3] *Materials Science & Engineering Department, Clemson University, Clemson, South Carolina 29634*

Chaos

Solitary waves

Chaotic orbits

Chaos

APPLIED PHYSICS LETTERS **104**, 234101 (2014)

Self-generation and management of spin-electromagnetic wave solitons and chaos

Alexey B. Ustinov, Alexandr V. Kondrashov, Andrey A. Nikitin, and Boris A. Kalinikos
Department of Physical Electronics and Technology, St. Petersburg Electrotechnical University, St. Petersburg 197376, Russia

(Received 18 March 2014; accepted 26 May 2014; published online 9 June 2014)

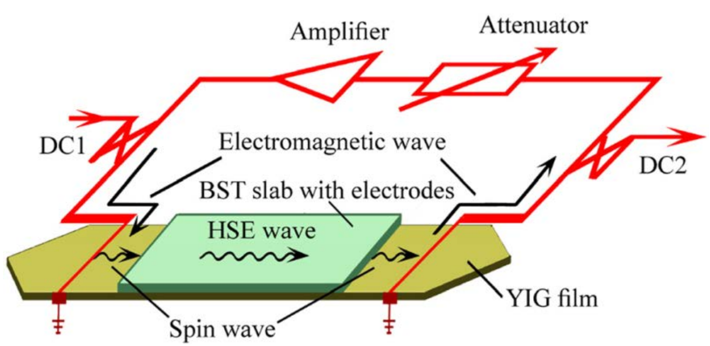


FIG. 1. Ferrite-ferroelectric active ring experimental structure.

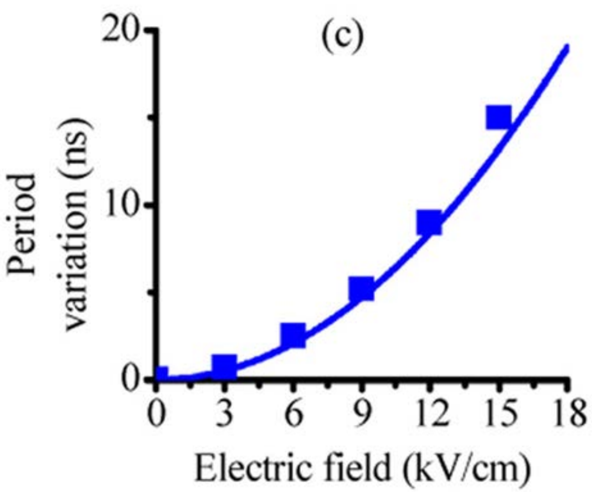


FIG. 4. (c) the variation of the soliton repetition period.

Infrared radiation and Thermoelectricity

Infrared radiation and Chaos

Thermoelectricity and Chaos

Infrared radiation and Thermoelectricity

Seebeck Nanoantennas for Solar Energy Harvesting

E. Briones[1,*], J. Briones[2], A. Cuadrado[3], J. C. Martinez-Anton[3], S. McMurtry[4], M. Hehn[4], F. Montaigne[4], J. Alda[3] and **F. J. Gonzalez**[1]

[1] CIACyT, Universidad Autonoma de San Luis Potosi, San Luis Potosi, 78210 SLP, Mexico

[2] Department of Mathematics and Physics, ITESO, Jesuit University of Guadalajara, 45604, Mexico

[3] Faculty of Optics and Optometry, Universidad Complutense de Madrid, 28037, Madrid, Spain

[4] Institut Jean Lamour, CNRS, Université de Lorraine, F-54506 Vandoeuvre Les Nancy, France

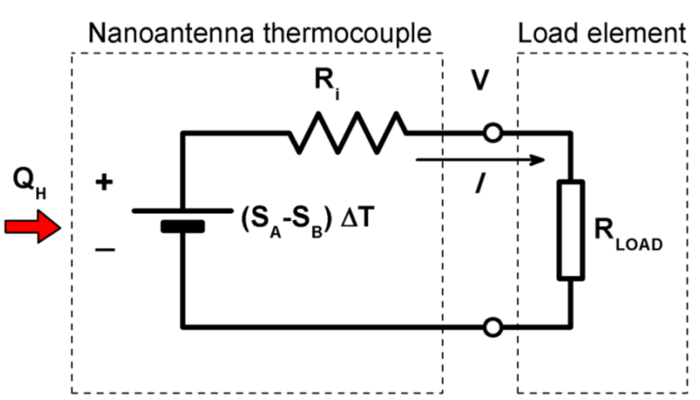


FIG. 2. DC equivalent circuit model of a Seebeck nanoantenna.

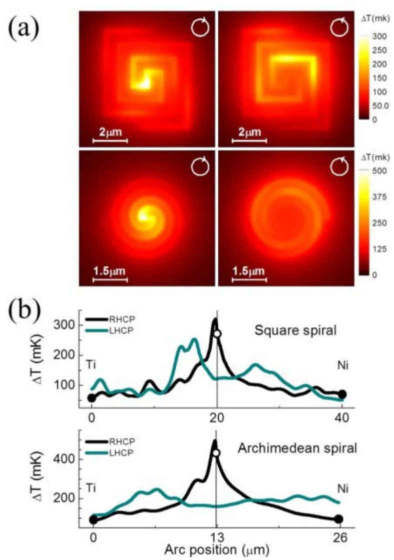


FIG. 3. **(a)** Temperature map of spirals Seebeck nanoantennas taken from a plane 50 nm below its surface. **(b)** Temperature profile all along the arms of the structures. The simulations were performed for two different polarization states: right-handed (RHCP) and left handed (LHCP) circular polarization of incident light at 10.6 μm.

Infrared radiation and Thermoelectricity

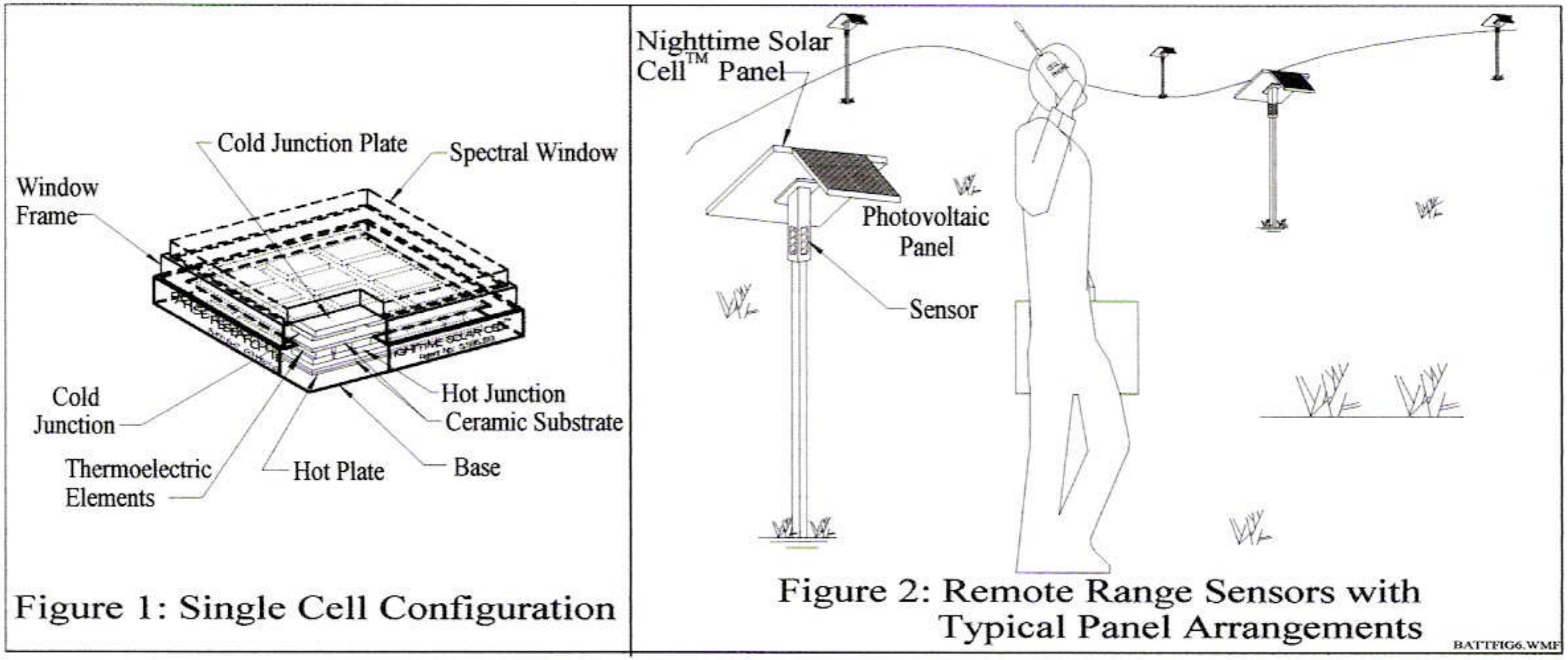


Figure 1: Single Cell Configuration

Figure 2: Remote Range Sensors with Typical Panel Arrangements

The Nighttime Solar Cell® by **R. J. Parise**

R. J. Parise and G. F. Jones, *Prototype data from the Nighttime solar cell™*, Collection of Technical papers – 2nd International Energy Conversion Engineering Conference, 1172–1181 (2004)

Infrared radiation and Thermoelectricity

Joseph R. Blandino, and David J. Lawrence

Transient response of a thermoelectric generator subjected to spatially non-uniform heating: implications for heat and IR sensing applications

Abstract:
We present a combined experimental and finite element computational investigation of the transient behavior of a **thermoelectric generator** (TEG) subjected to small temperature gradients of less than 0.5 K across its thickness. Spatially non-uniform heating was initiated by allowing light to strike the central portion of one side of the TEG or by placing a small heated probe in contact with that surface. The time-dependent, open circuit voltage output of the TEG was predicted using temperature results from a three dimensional transient heat conduction finite element model. Three-dimensional heat conduction in the TEG determines the nature of the transient voltage output, which, in some cases, exhibits an overshoot.

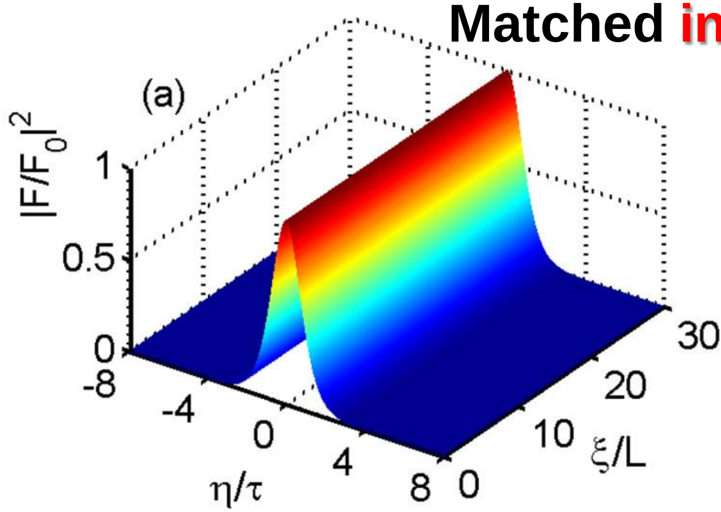
Joseph R. Blandino, Department of Mechanical Engineering, **Virginia Military Institute**, Lexington, VA 24450
David J. Lawrence, Department of Integrated Science and Technology and Center for Materials Science, **James Madison University**, Harrisonburg, VA 22807

Infrared radiation and Chaos

PHYSICAL REVIEW A **90**, 043819 (2014)

Matched infrared soliton pairs in graphene under Landau quantization via four-wave mixing

Chunling Ding,[1] Rong Yu,[2] Jiahua Li,[3,4,*] Xiangying Hao,[2] and Ying Wu [3,†]
[1]*School of Physics and Electronics, Henan University, Kaifeng 475004*
[2]*School of Science, Hubei Province Key Laboratory of Intelligent Robot, Wuhan Institute of Technology, Wuhan 430073*
[3]*Wuhan National Laboratory for Optoelectronics and School of Physics, Huazhong University of Science and Technology, Wuhan 430074*
[4]*MOE Key Laboratory of Fundamental Quantities Measurement, Wuhan 430074*
All from ***People's Republic of China***



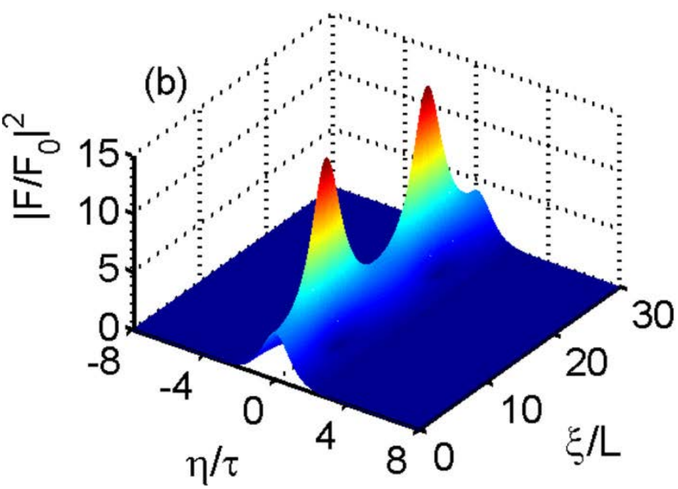


FIG. 4. Surface plots of the relative intensities of pulsed probe and FWM fields versus dimensionless time η/τ and distance ξ/L for
(a) the fundamental **bright soliton** and
(b) the **bright soliton of second order**, which is obtained by numerically solving Eq. (36) without ignoring the imaginary part of coefficients with
$L = 0.1$ cm, $\tau = 3.33 \times 10{-}14$ s, and
other parameters are explained in the text.

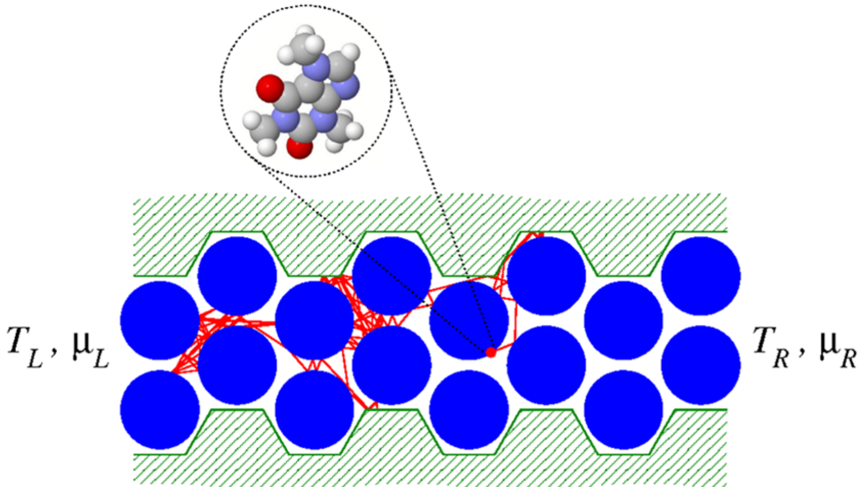
Thermoelectricity and Chaos

PHYSICAL REVIEW LETTERS **101,** 016601 (2008)

Increasing Thermoelectric Efficiency: A Dynamical Systems Approach

Giulio Casati,[1,2] Carlos Mejı´a-Monasterio,[3] and Tomazˇ Prosen [4]
[1]*Center for Nonlinear and Complex Systems, Universita` degli Studi dell'Insubria, Como, Italy*
[2]*CNR-INFM and Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Milan, Italy*
[3]*De´partement de Physique The´orique, Universite´ de Gene`ve, Geneva, Switzerland*
[4]*Physics Department, Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia*

Inspired by the **kinetic theory of ergodic gases and chaotic billiards**, we propose a simple microscopic mechanism for the increase of **thermoelectric efficiency**. We consider the cross transport of particles and energy in open classical ergodic billiards. We show that, in the linear response regime, where we find exact expressions for all transport coefficients, the thermoelectric efficiency of ideal ergodic gases can approach the Carnot efficiency for sufficiently complex charge carrier molecules. Our results are clearly demonstrated with a simple numerical simulation of a Lorentz gas of particles with internal rotational degrees of freedom.



Infrared radiation,
Thermoelectricity,
and Chaos … ???

… and transform the infrared radiation into usable energy…

… and transform the **infrared radiation** into usable energy…

Battery-assisted and Photovoltaic-sourced Switched-inductor CMOS Harvesting Charger–Supply

Rajiv D. Prabha, and **Gabriel A. Rincón-Mora**
Georgia Institute of Technology, Atlanta, Georgia 30332 U.S.A. (2011)

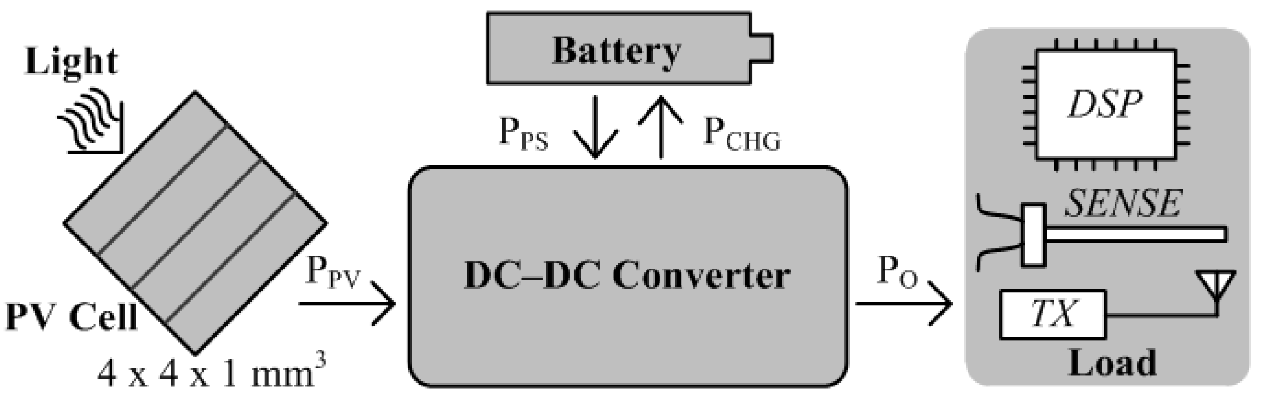


FIG. 1. Battery-assisted and photovoltaic-sourced wireless microsensor.

… and transform the **infrared radiation** into usable energy…

Self-powered signal processing using vibration-based power generation
R. Amirtharajah and A. P. Chandrakasan
IEEE Journal of Solid-State Circuits **33** (5), 687-695,(1998)

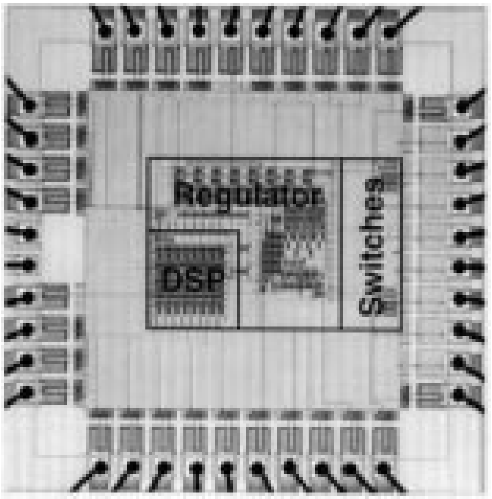


FIG. 17. A die photo of the chip which integrates the load DSP, the critical path VCO, the regulator circuit, and the power switches. The controller is fairly simple, requiring only 2247 transistors out of the 5k total number.

Infrared radiation, Thermoelectricity, and Chaos

Infrared power generation:

fundamental understanding, applications and benefits

Giovanna Scarel

Department of Physics and Astronomy

James Madison University

Workshop on Infrared Radiation, Thermoelectricity, and Chaos

James Madison University, June 17, 2015

Outline

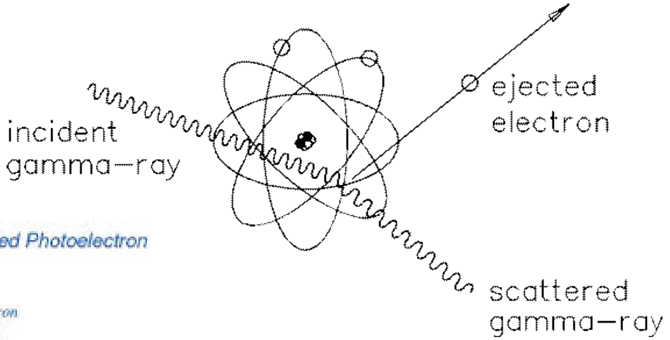
- Infrared
- Infrared and thermoelectricity
- Infrared, thermoelectricity and chaos
- Results-I
- Results-II
- Conclusions
- Acknowledgements

Infrared

High energy electromagnetic radiation and matter $(\mathbf{S} = \mathbf{E} \times \mathbf{H})$

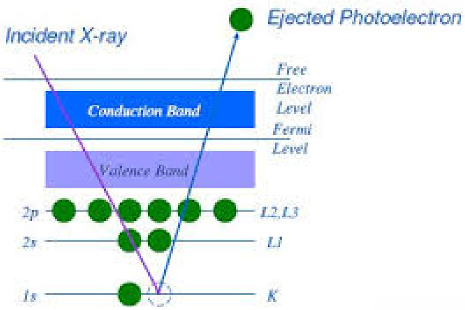
Compton scattering

γ rays →



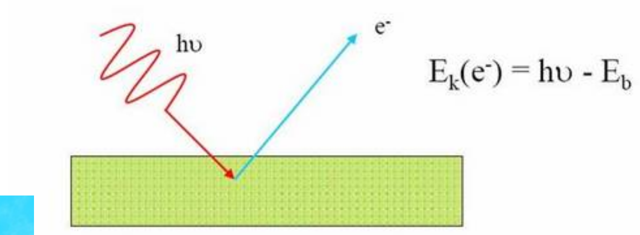
X-ray photoelectron spectroscopy

X rays →



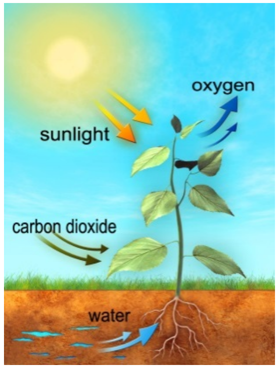
Photoelectric effect

ultraviolet rays →



Photosynthesis

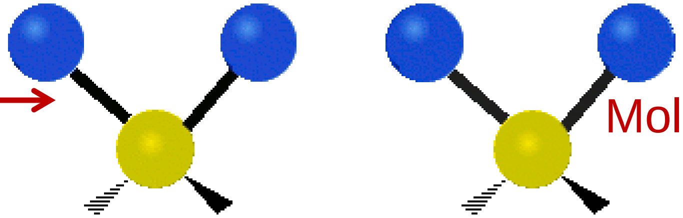
visible light →



Infrared

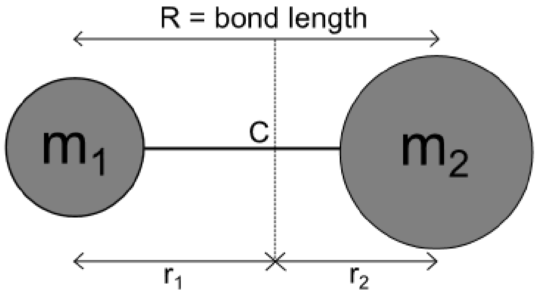
Low energy electromagnetic radiation and matter $(\mathbf{S} = \mathbf{E} \times \mathbf{H})$

infrared radiation →



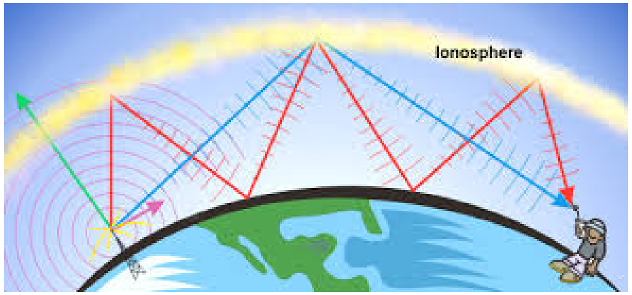
Molecular and crystal vibrations

microwaves →



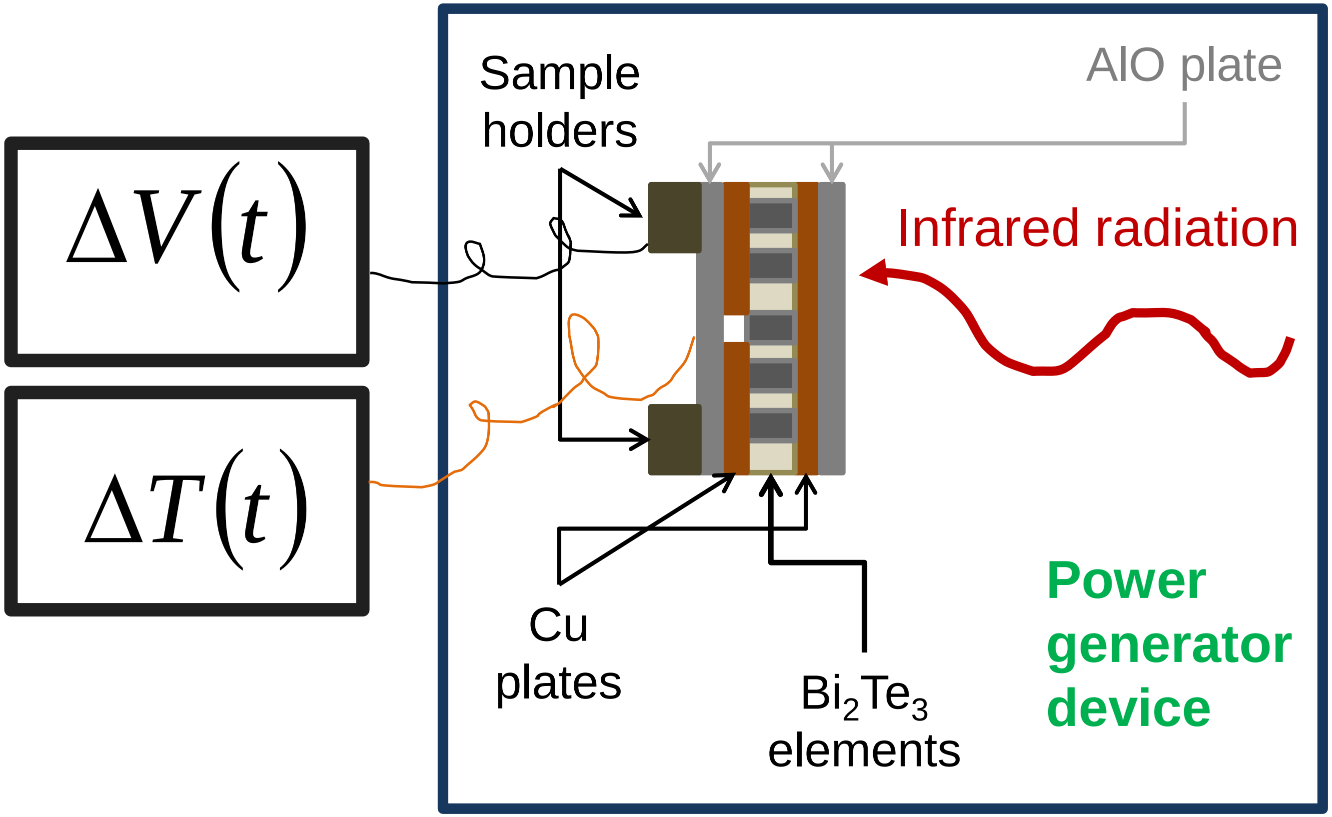
Molecular rotations (causing entropy)

radiowaves →



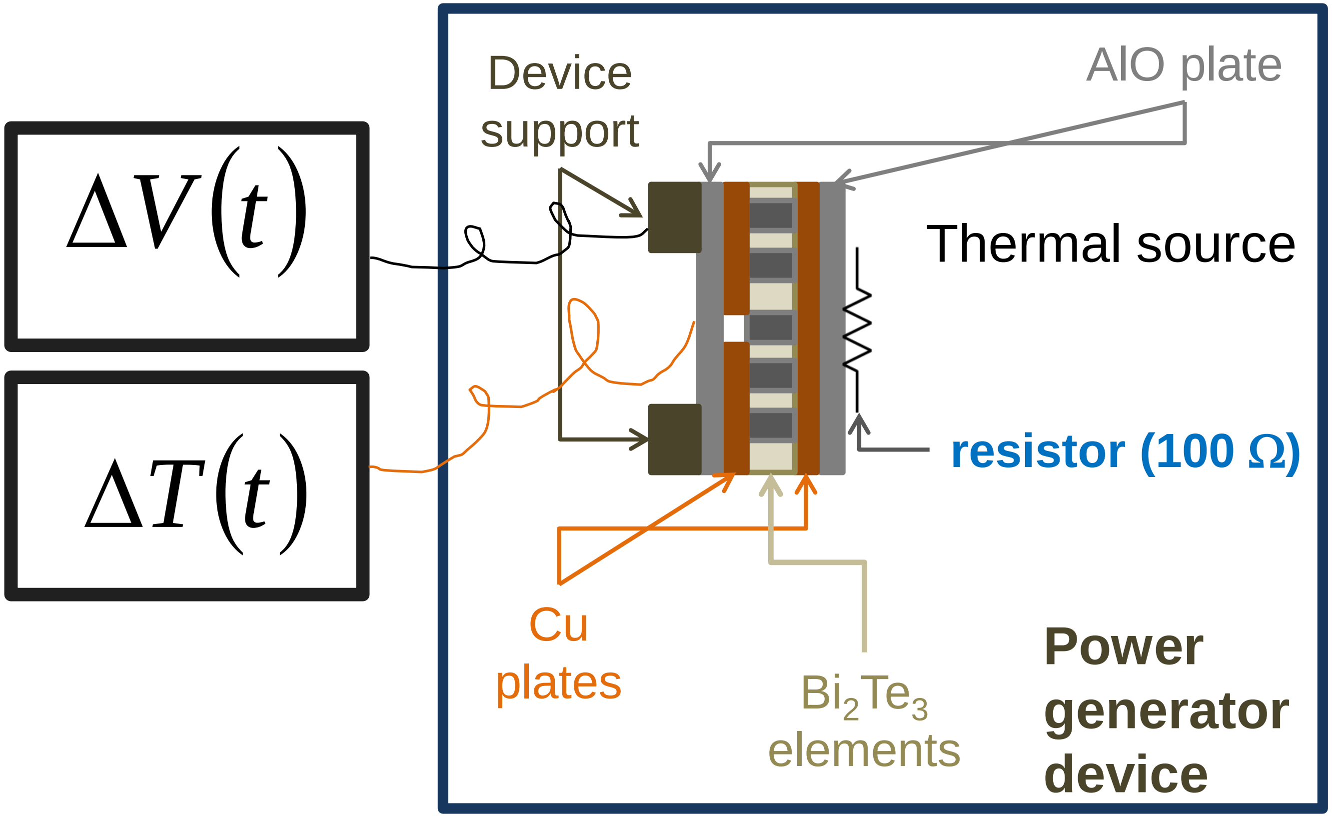
Infrared and Thermoelectricity

Experimental method:



Infrared and Thermoelectricity

Experimental method:

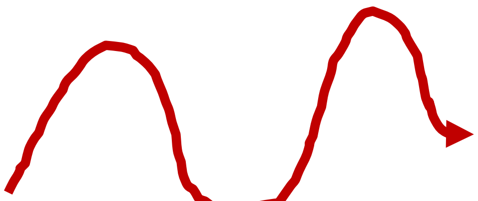


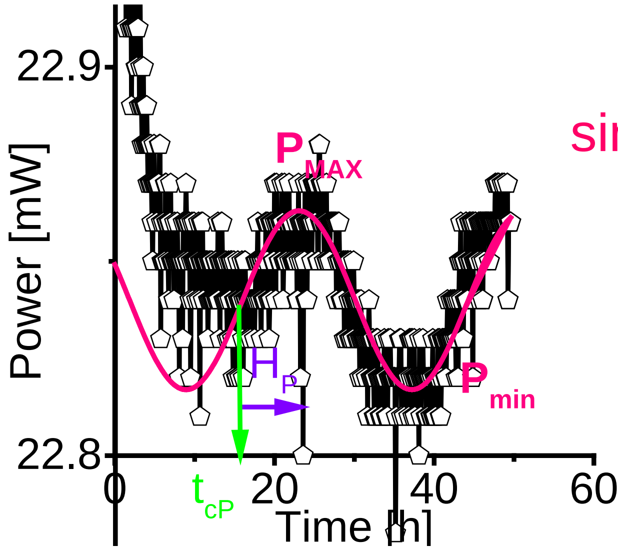
Here conductive and convective heat transfer coexist!

What is the **key** to connect
Infrared radiation,
to Thermoelectricity
and Chaos?

Infrared, Thermoelectricity and Chaos

Infrared radiation



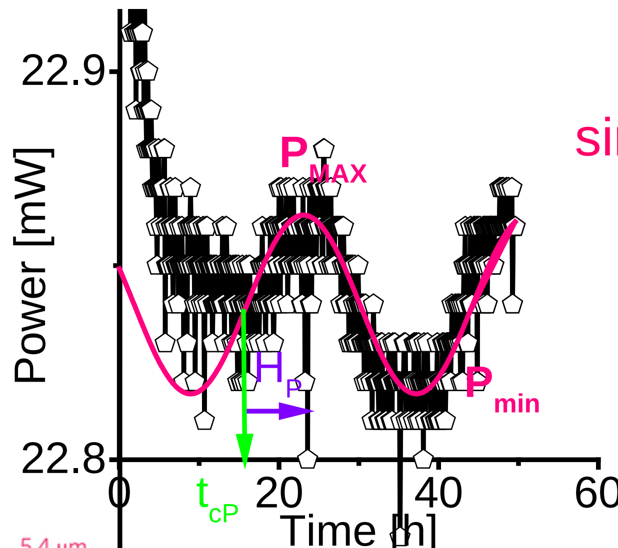


sinusoidal temporal instability

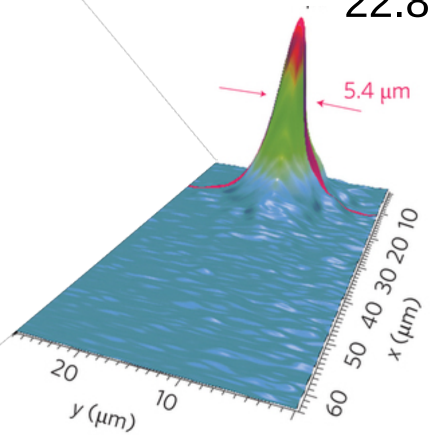
A.L. Gordon, Y. Schwab, B.N. Lang, G.P. Gearhart, T.R. Jobin, J.M. Kaczmar, K. A. Britton, H.S. Mann, Z.J. Marinelli, B.C. Utter, and G. Scarel, *Decoupling the electrical and entropic contributions to energy transfer from infrared radiation to a power generator*, to be submitted to **Chaos, Solitons & Fractals**.

Infrared, Thermoelectricity and Chaos

Infrared radiation



sinusoidal temporal instability

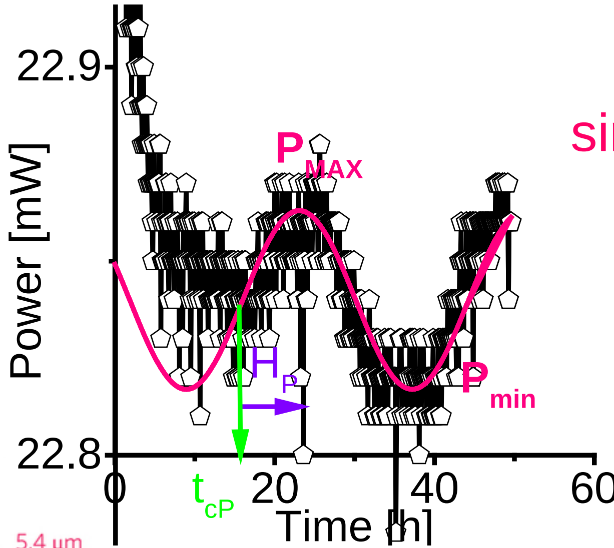


Soliton of surface charge density $\sigma(\mathbf{r},t) \propto$
$\propto \mathrm{sech}[f(\mathbf{r},t)]$

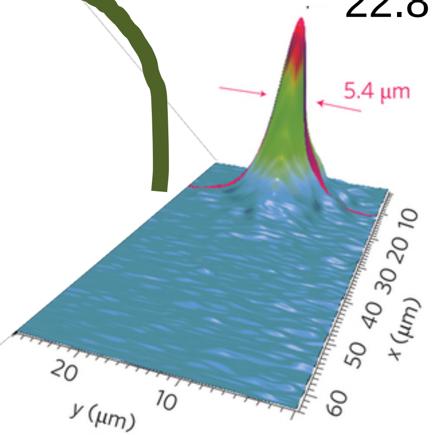
A.L. Gordon, Y. Schwab, B.N. Lang, G.P. Gearhart, T.R. Jobin, J.M. Kaczmar, K. A. Britton, H.S. Mann, Z.J. Marinelli, B.C. Utter, and G. Scarel, *Decoupling the electrical and entropic contributions to energy transfer from infrared radiation to a power generator*, to be submitted to **Chaos, Solitons & Fractals**.

Infrared, Thermoelectricity and Chaos

Infrared radiation



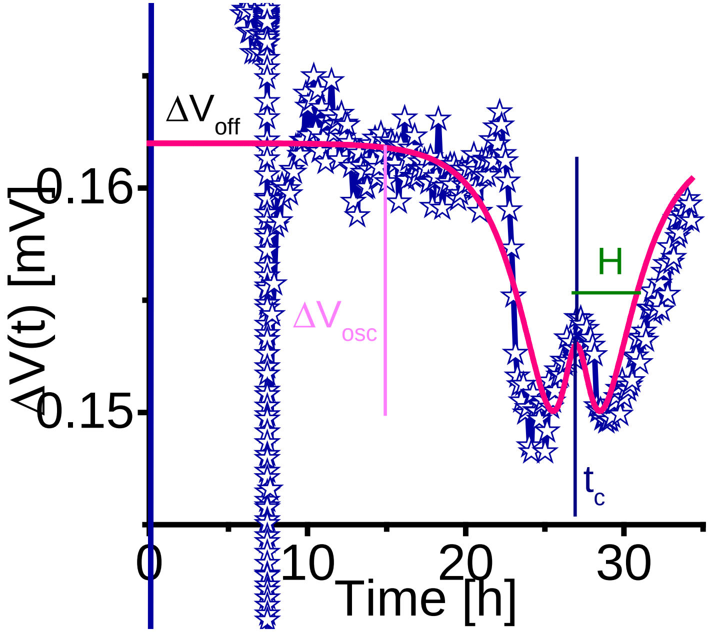
sinusoidal temporal instability



Soliton of surface charge density $\sigma(\mathbf{r},t) \propto$ $\propto \mathrm{sech}[f(\mathbf{r},t)]$

A.L. Gordon, Y. Schwab, B.N. Lang, G.P. Gearhart, T.R. Jobin, J.M. Kaczmar, K. A. Britton, H.S. Mann, Z.J. Marinelli, B.C. Utter, and G. Scarel, *Decoupling the electrical and entropic contributions to energy transfer from infrared radiation to a power generator*, to be submitted to **Chaos, Solitons & Fractals**.

Infrared, Thermoelectricity and Chaos



$$\Delta V(t) = \sum_{j=1}^{L} \Delta V_{off-j} + \Delta V_{osc-j} * \mathrm{sech}\left(\frac{t - t_{c-j}}{H_j}\right)$$

A.L. Gordon, Y. Schwab, B.N. Lang, G.P. Gearhart, T.R. Jobin, J.M. Kaczmar, K. A. Britton, H.S. Mann, Z.J. Marinelli, B.C. Utter, and G. Scarel, *Decoupling the electrical and entropic contributions to energy transfer from infrared radiation to a power generator*, to be submitted to **Chaos, Solitons & Fractals**.

Infrared, Thermoelectricity and Chaos

$$\Delta V(t) = \sum_{j=1}^{L} \Delta V_{off-j} + \Delta V_{osc-j} * \sec h\left(\frac{t - t_{c-j}}{H_j}\right)$$

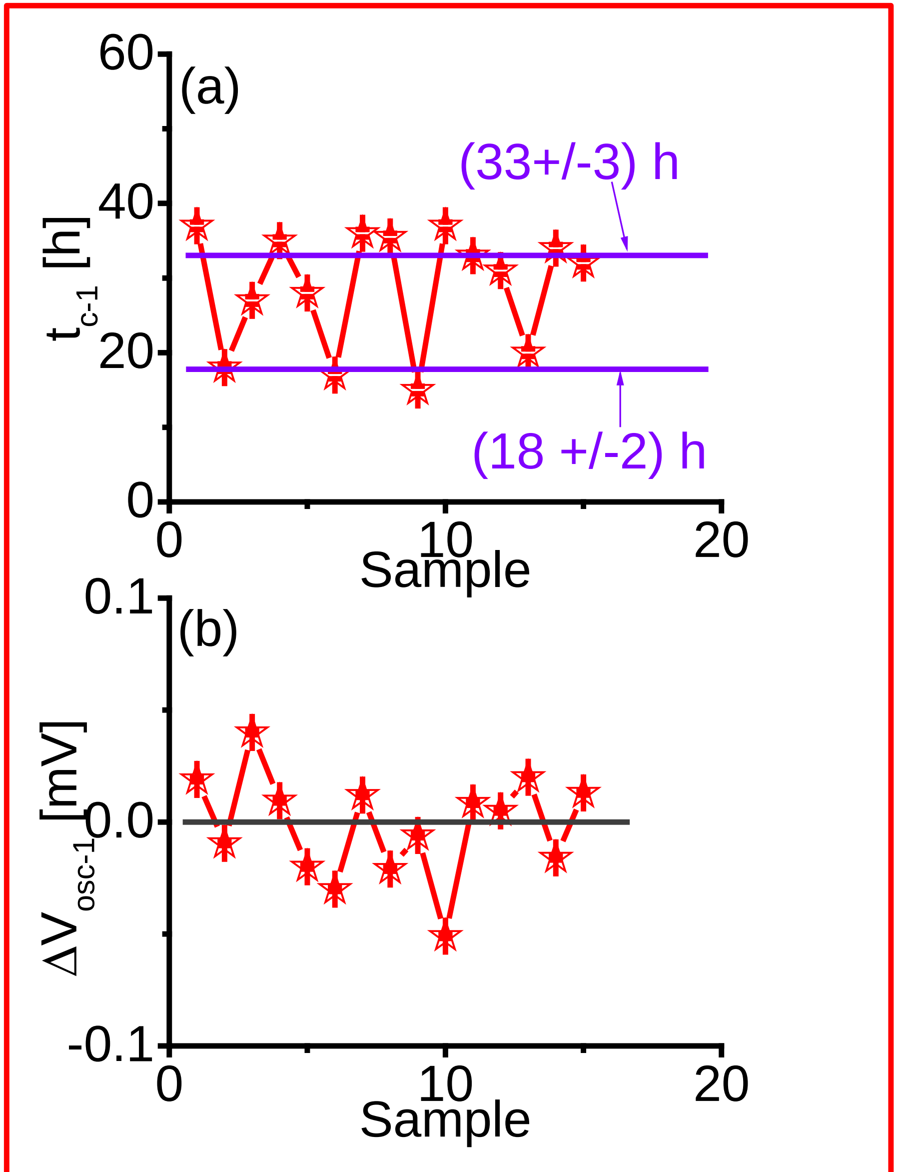
Anomalous soliton, solution of the “flipped” Korteweg de Vries equation:

$$\sigma(t)\Delta V(t)\frac{\partial \Delta V(t)}{\partial t} + \varsigma(t)\frac{\partial^3 \Delta V(t)}{\partial t^3} = 0$$

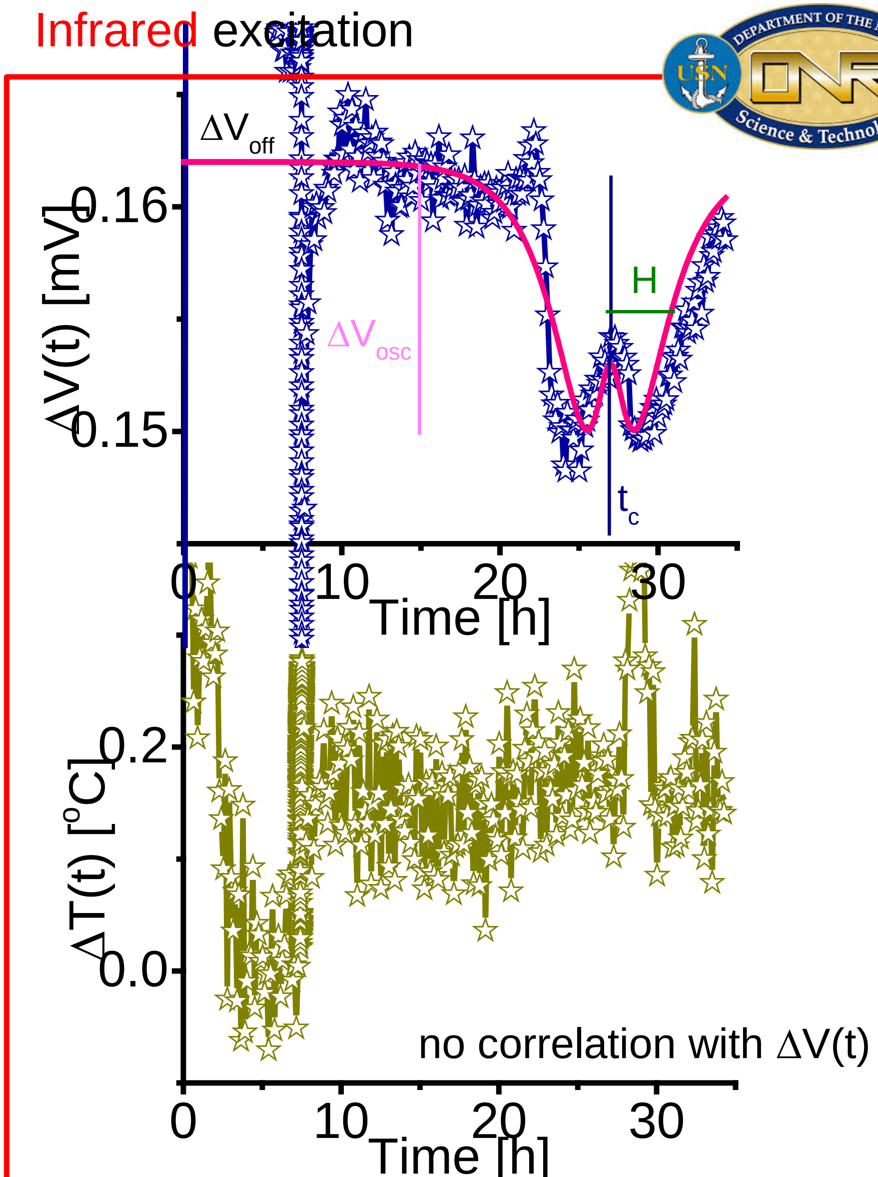
A.L. Gordon, Y. Schwab, B.N. Lang, G.P. Gearhart, T.R. Jobin, J.M. Kaczmar, K. A. Britton, H.S. Mann, Z.J. Marinelli, B.C. Utter, and G. Scarel, *Decoupling the electrical and entropic contributions to energy transfer from infrared radiation to a power generator*, to be submitted to **Chaos, Solitons & Fractals**.

Results - I

Infrared excitation

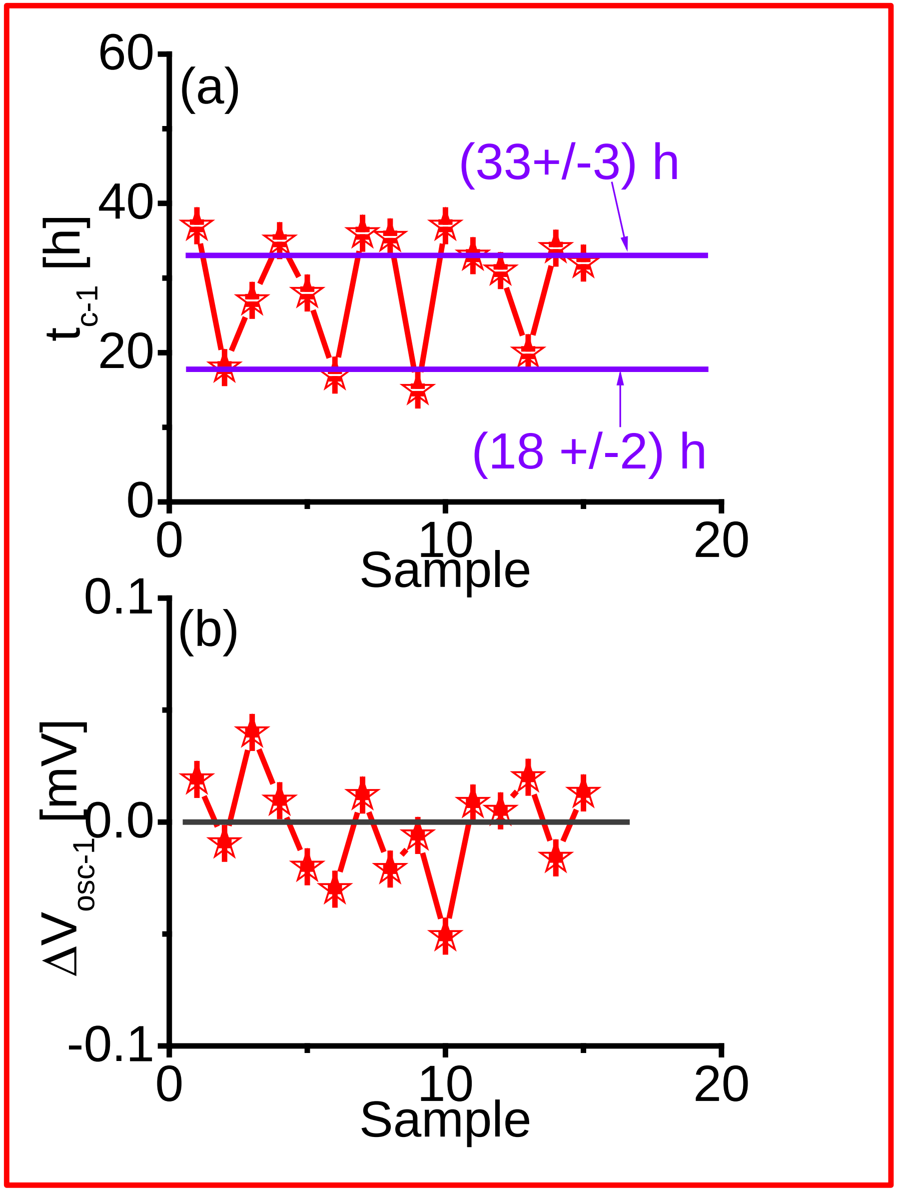


Infrared excitation

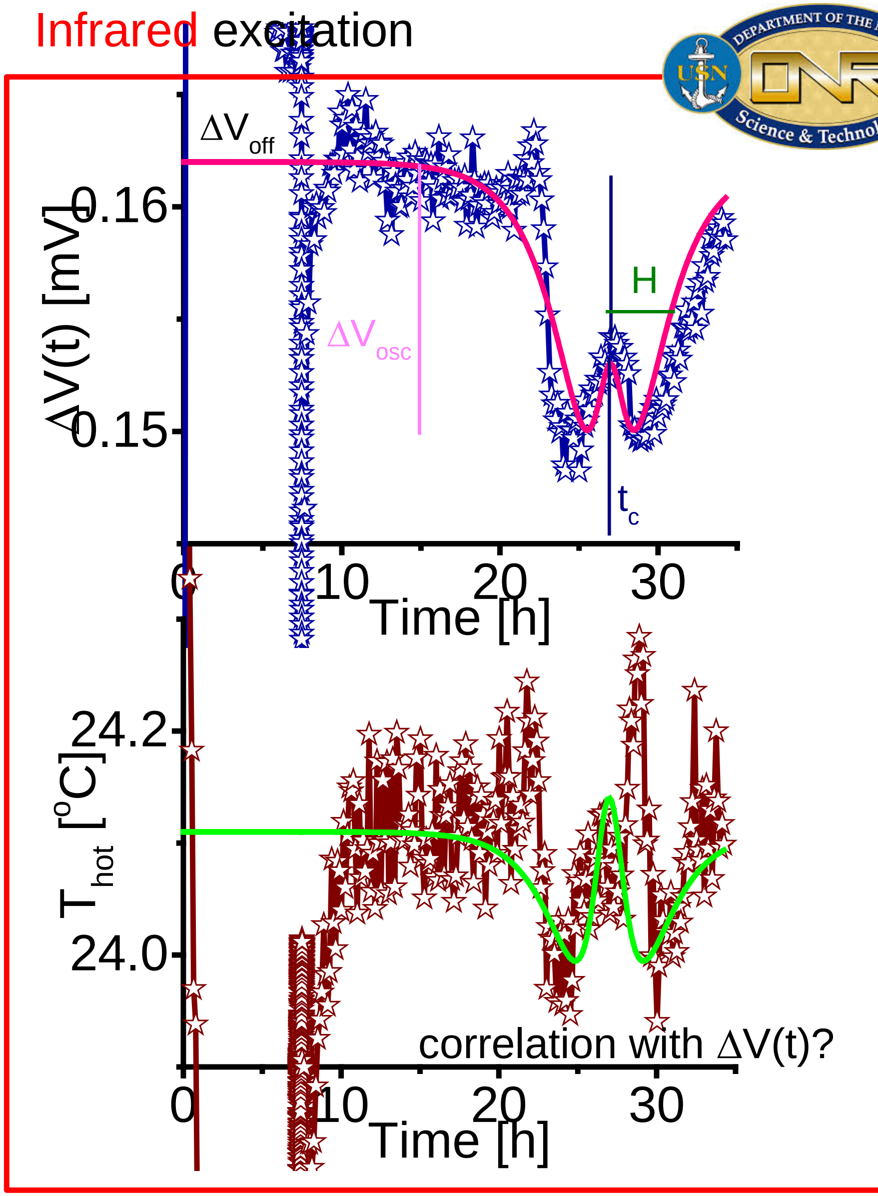


Results - I

Infrared excitation

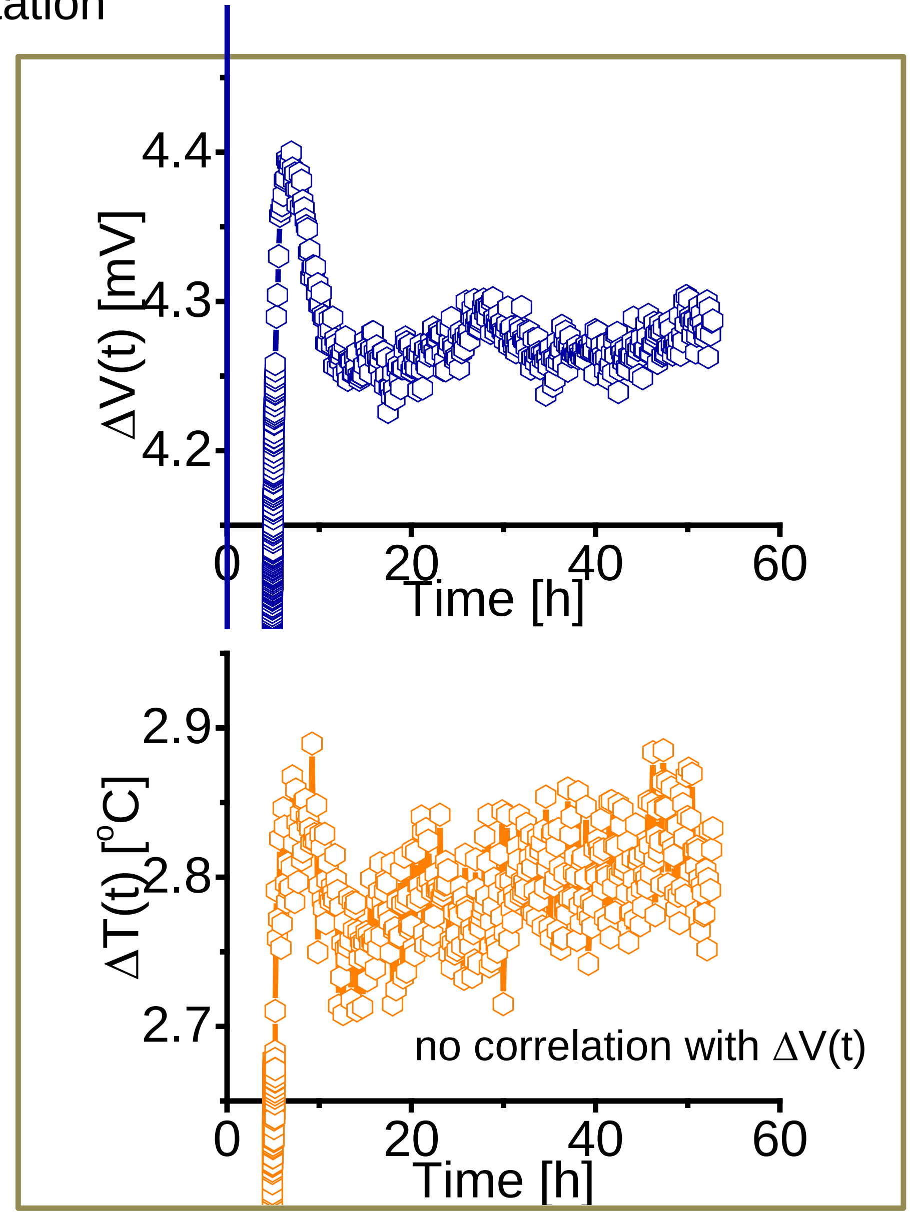


Infrared excitation



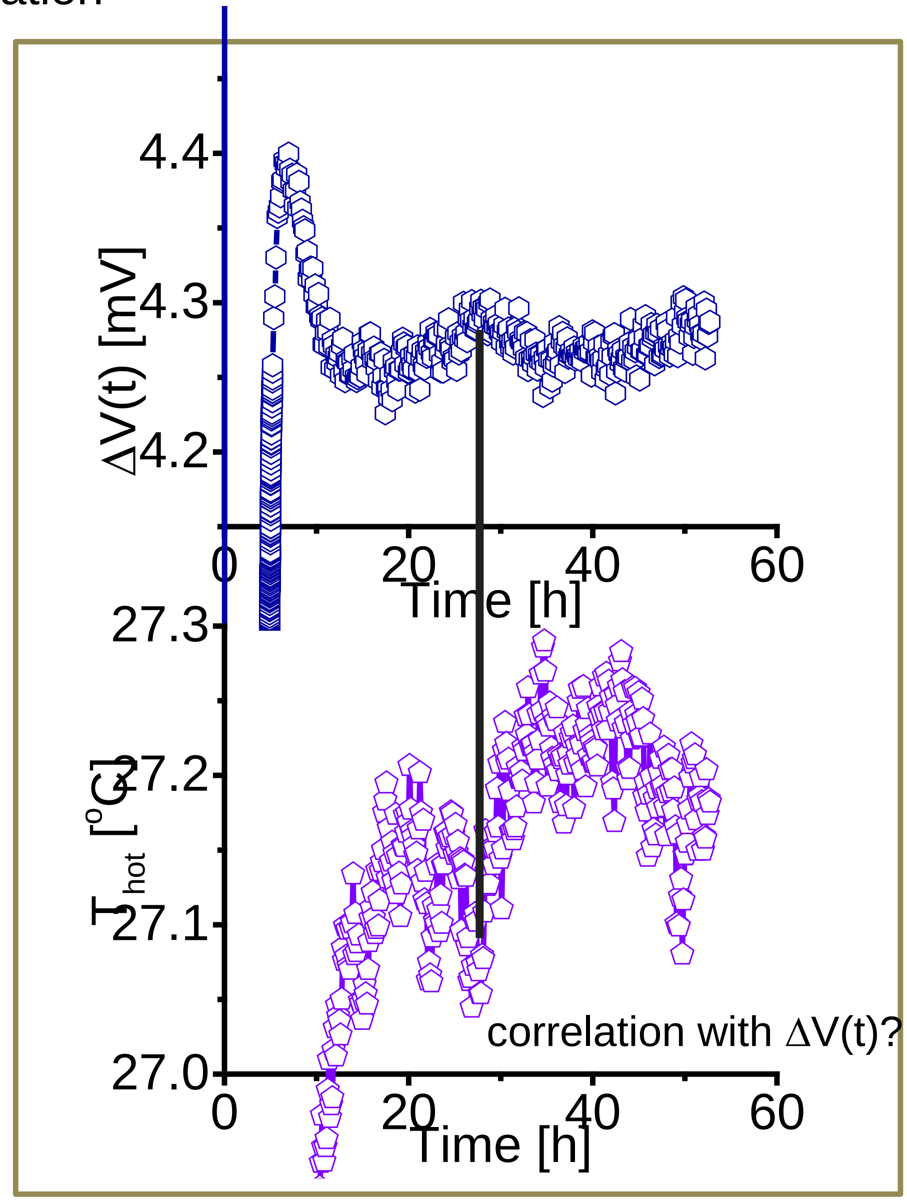
Results - I

Thermal excitation



Results - I

Thermal excitation



Results - I

Electric contribution:

$$\Delta E(t)_{el} = \sigma(\mathbf{r},t)\Delta V(t)$$

$\sigma(\mathbf{r}, t)$ = charge density
$\Delta V(t)$ = voltage difference

affects T_{hot} through motion of charges

Entropic contribution:

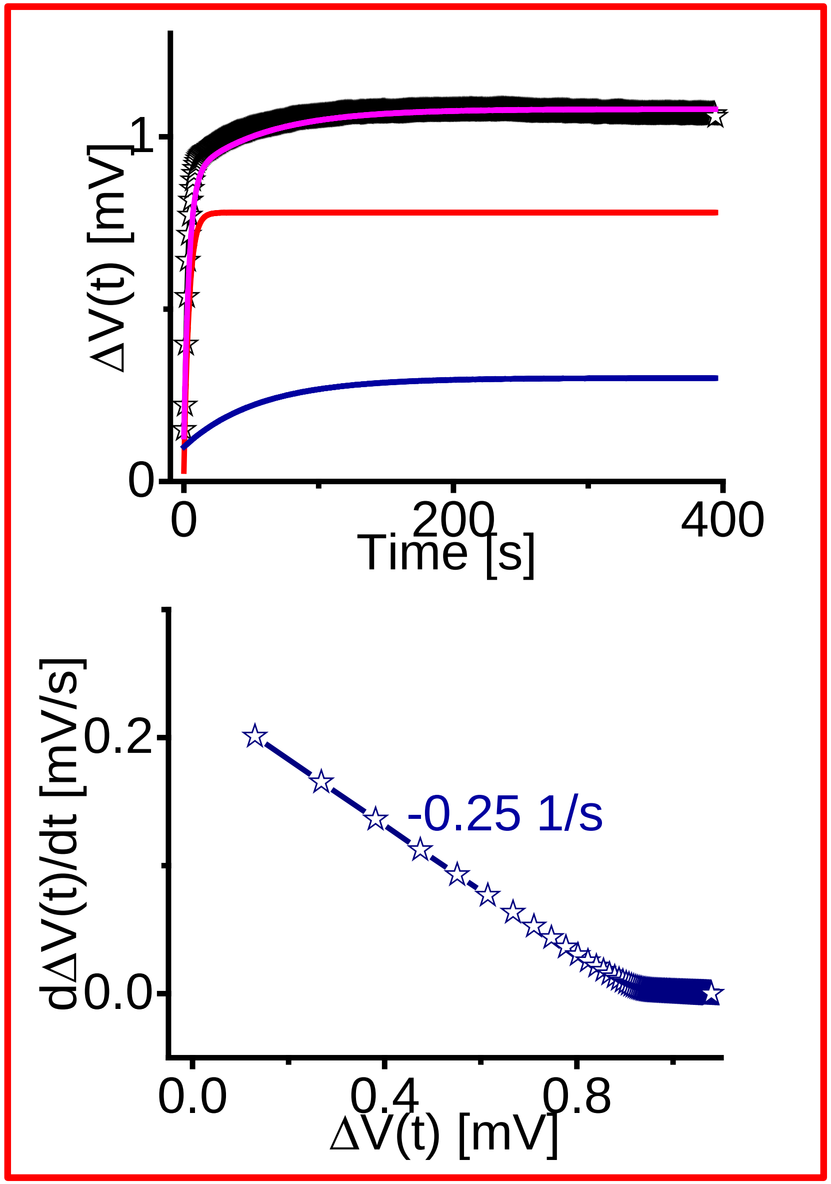
$$\Delta E(t)_{en} = \Sigma(t)\Delta T(t)$$

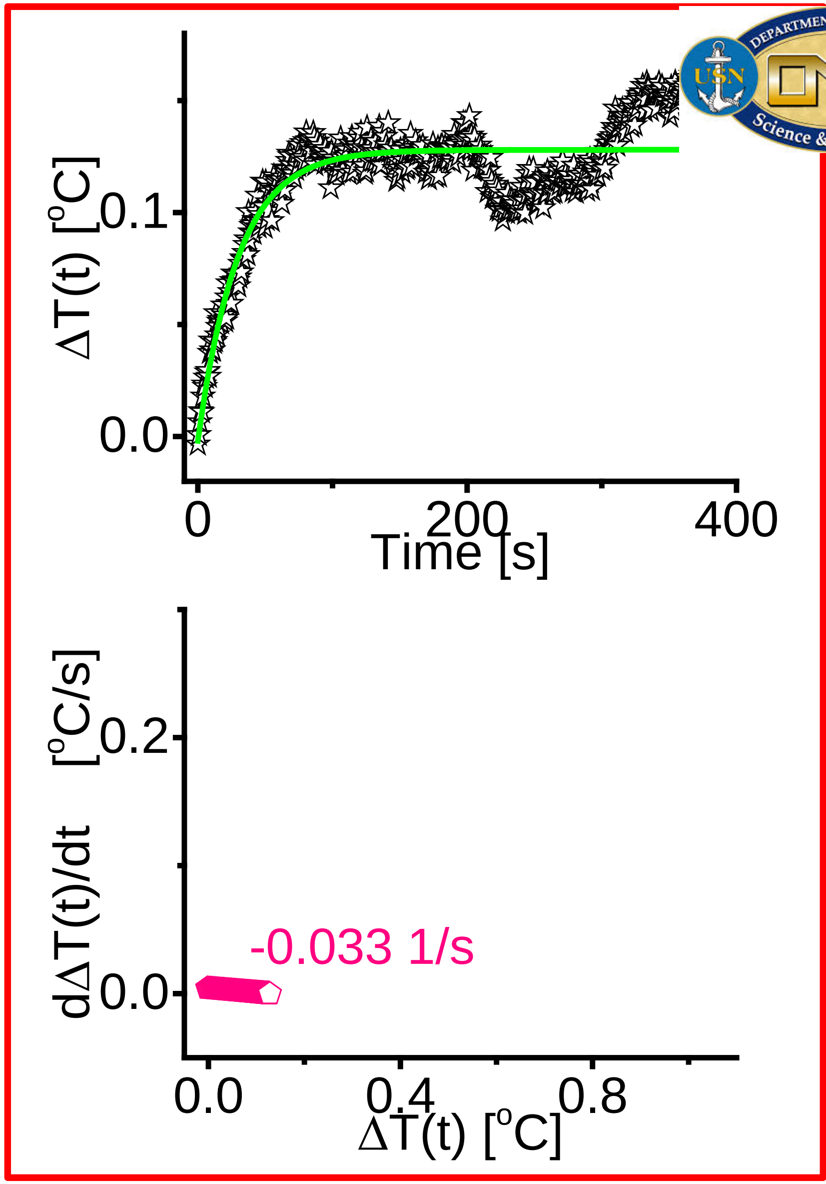
$\Sigma(t)$ = entropy
$\Delta T(t)$ = temperature difference

A.L. Gordon, Y. Schwab, B.N. Lang, G.P. Gearhart, T.R. Jobin, J.M. Kaczmar, K. A. Britton, H.S. Mann, Z.J. Marinelli, B.C. Utter, and G. Scarel, *Decoupling the electrical and entropic contributions to energy transfer from infrared radiation to a power generator*, to be submitted to **Chaos, Solitons & Fractals**.

Results - II

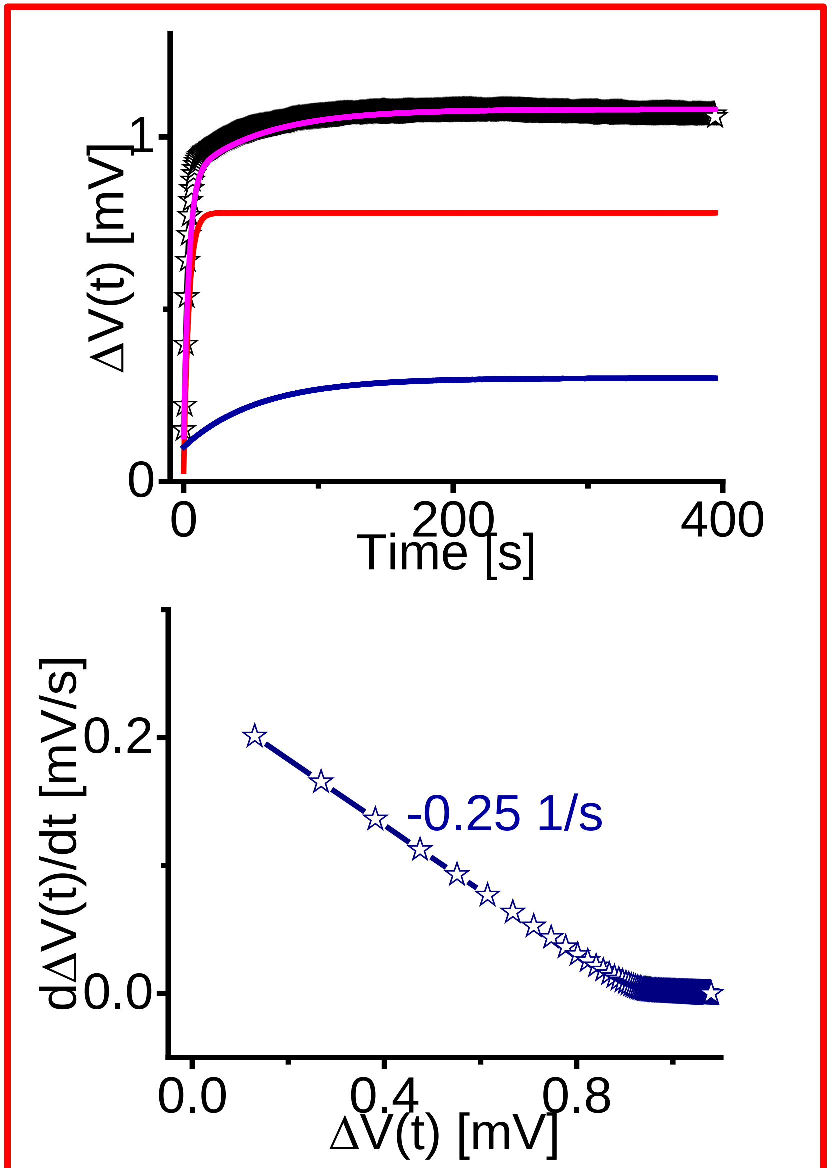
Infrared excitation

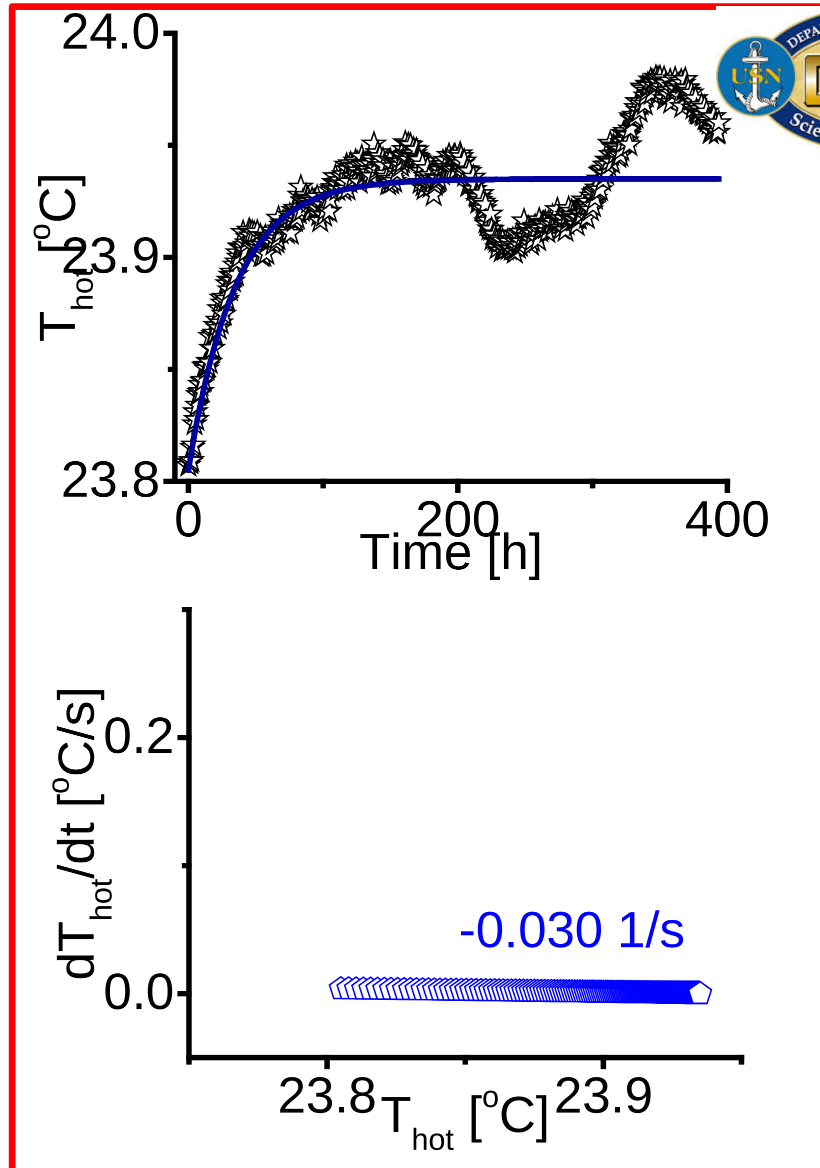




Results - II

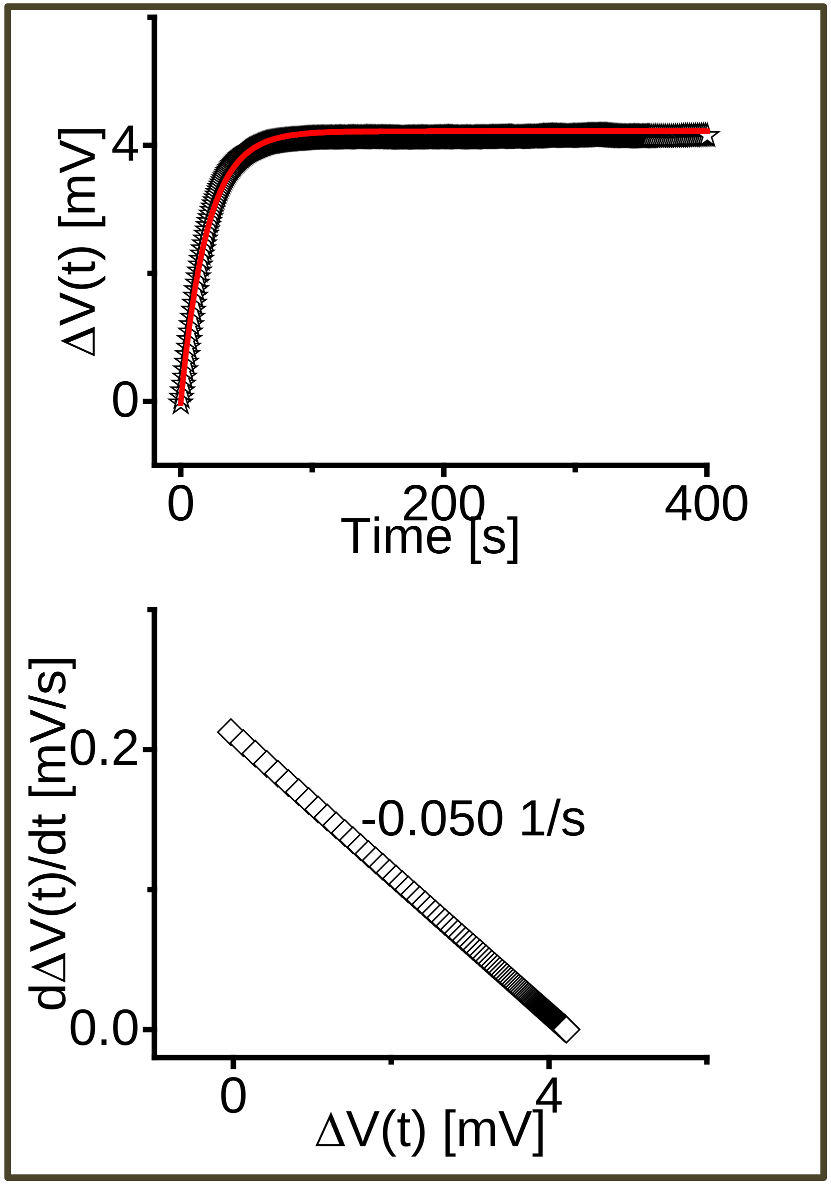
Infrared excitation

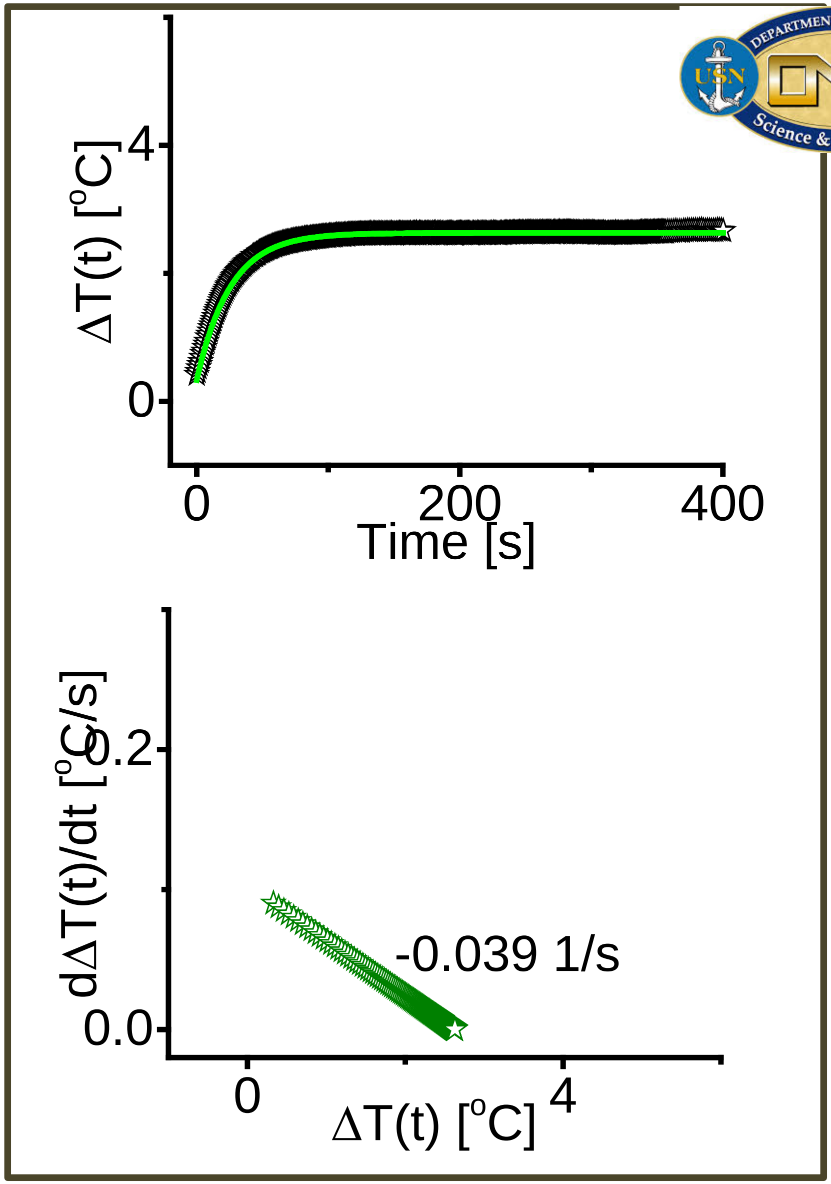




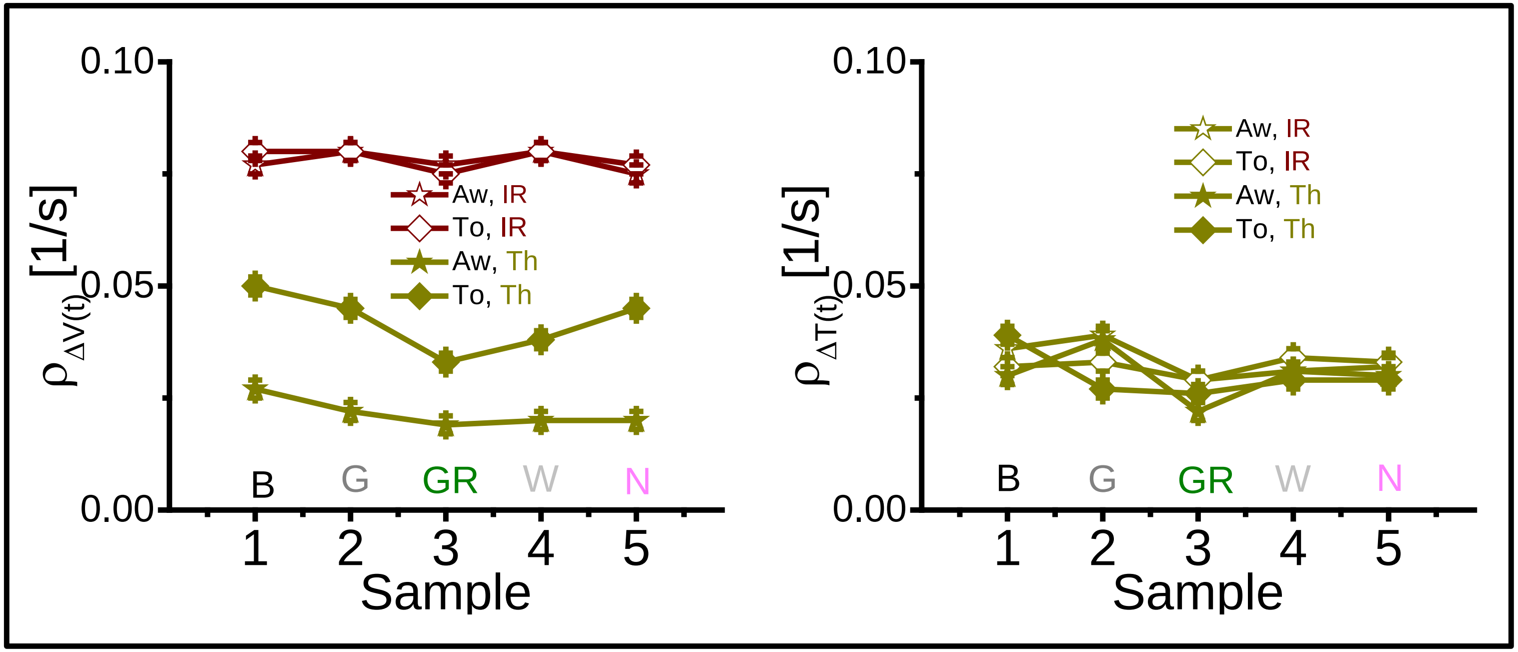
Results - II

Thermal excitation





Results - II



$\rho_{\Delta V(t)}$ and $\rho_{\Delta T(t)}$ are the rates of increase of voltage and temperature differences

We acknowledge an electric and an entropic contribution to the energy transfer from infrared radiation to the device

A.L. Gordon, Y. Schwab, B.N. Lang, G.P. Gearhart, T.R. Jobin, J.M. Kaczmar, K. A. Britton, H.S. Mann, Z.J. Marinelli, B.C. Utter, and G. Scarel, *Decoupling the electrical and entropic contributions to energy transfer from infrared radiation to a power generator*, to be submitted to **Chaos, Solitons & Fractals**.

Results - II

Electric contribution:

$$\Delta E(t)_{el} = \sigma(\mathbf{r}, t)\Delta V(t)$$

$\sigma(\mathbf{r}, t)$ = charge density
$\Delta V(t)$ = voltage difference

Entropic contribution:

$$\Delta E(t)_{en} = \Sigma(t)\Delta T(t)$$

$\Sigma(t)$ = entropy
$\Delta T(t)$ = temperature difference

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Conclusions

Voltage difference $\Delta V(t)$ production:

1) Not limited by the **entropic** contribution through ΔT

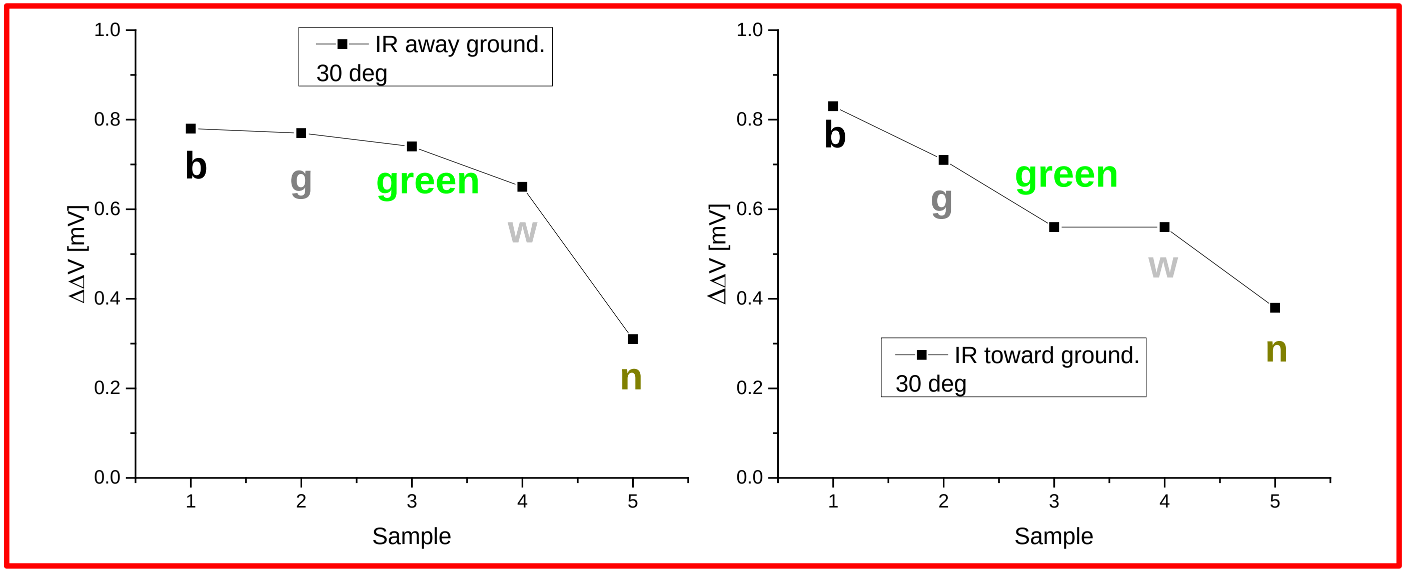
2) enhanced by the **electric** contribution!

Example 1: **$\Delta V(t)$ increase** versus of vinyl-based plastic **tape color** on illuminated face of power generator device

Example 2: **$\Delta V(t)$ increase** versus **number** of serially stacked power generator devices

Conclusions-I

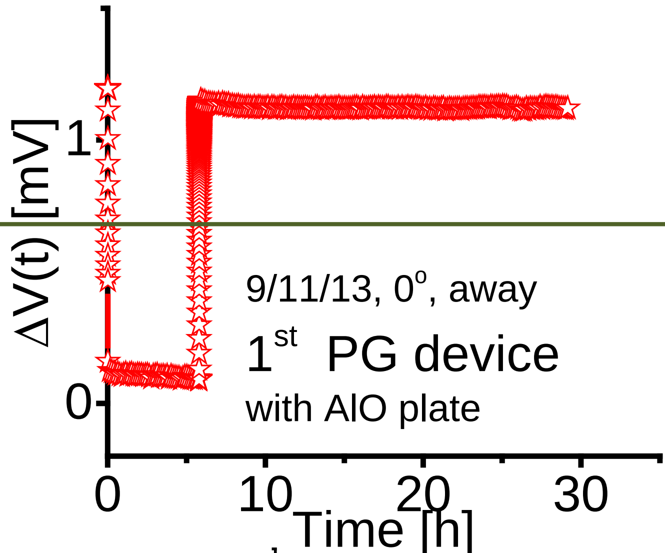
Example 1: **ΔV(t) increase** versus of vinyl-based plastic **tape color** on illuminated face of power generator device

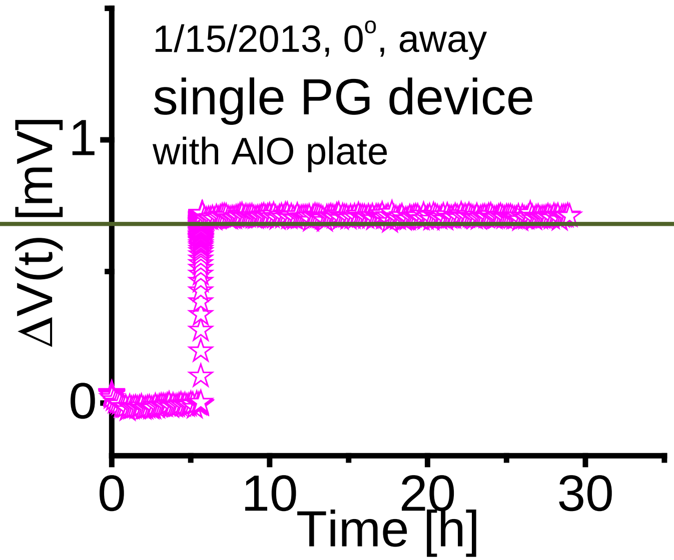


Infrared

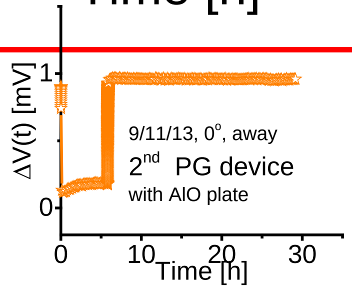
Conclusions-II

Example 2: **ΔV(t) increase** versus **number** of serially stacked power generator devices





Infrared



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Yosyp Schwab
Harkirat S Mann
Brian N. Lang
Graham P. Gearhart
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