THErmalization, TRAnsport and COMplexity at nanoscale (THETRACOM)

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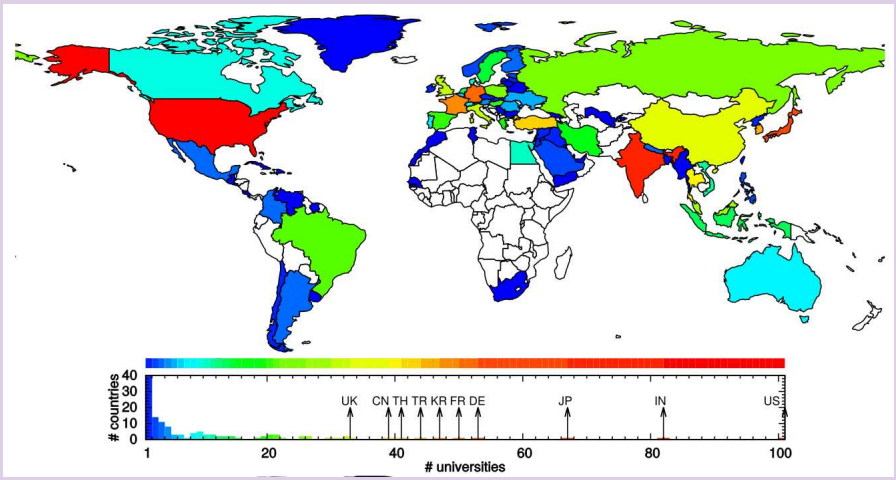
+ Katia Jaffres-Runser (N7-IRIT), D.Demidov (RAS Kazan), A.Chepelianskii (LPS)

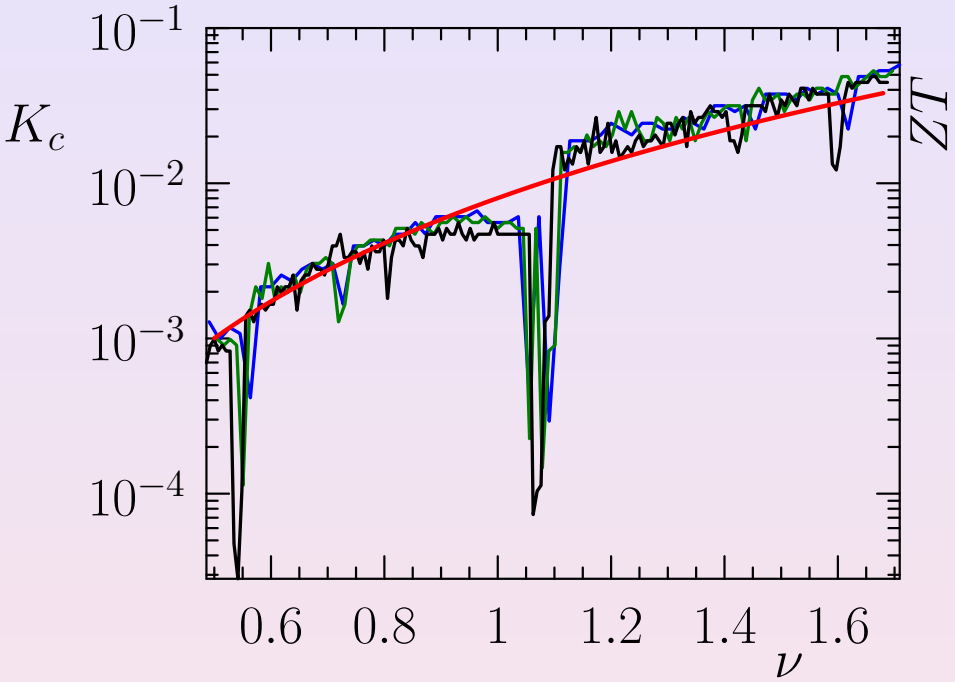


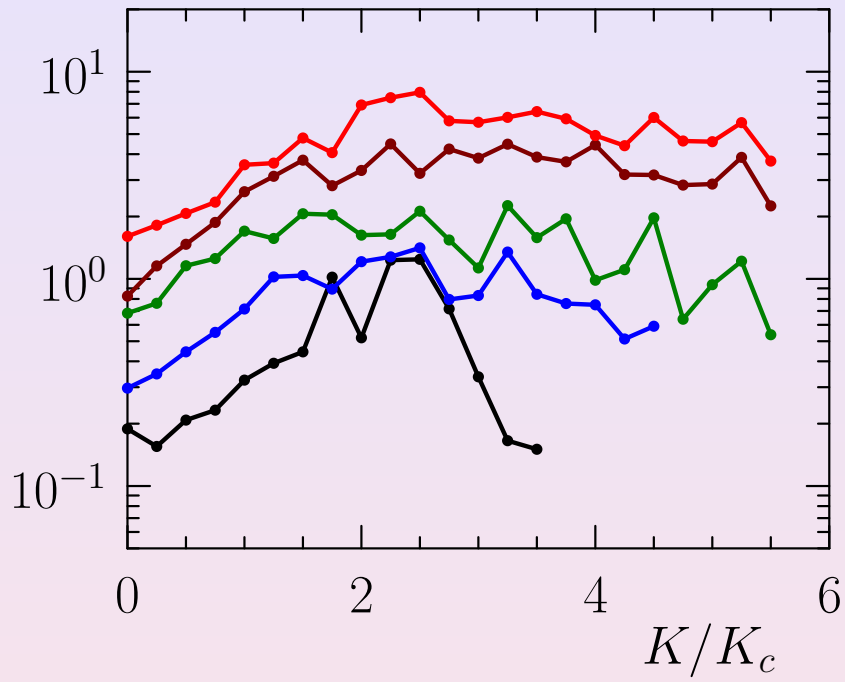
WRWU: J.Lages, DLS *et al.*
EPJB (2016, 2019) [24 Wikis]
100 press highlights of 22 countries

- Systems: Thermoelectricity, electron transport, interacting fermions, Wigner crystal in a periodic potential, MIRO and Zero resistance states, cold ions transport on directed networks *et al.*
- Results 2017-2020: $ZT \approx 8 > 2.6$ maximum observed in material science; theory of microwave polarization dependence of MIRO; dynamical thermalization of cold atoms in Sinai oscillator trap, methods of Google matrix analysis ...

Support: NEXT THETRACOM (39keuro/30publications in 3 years 20017-2020)

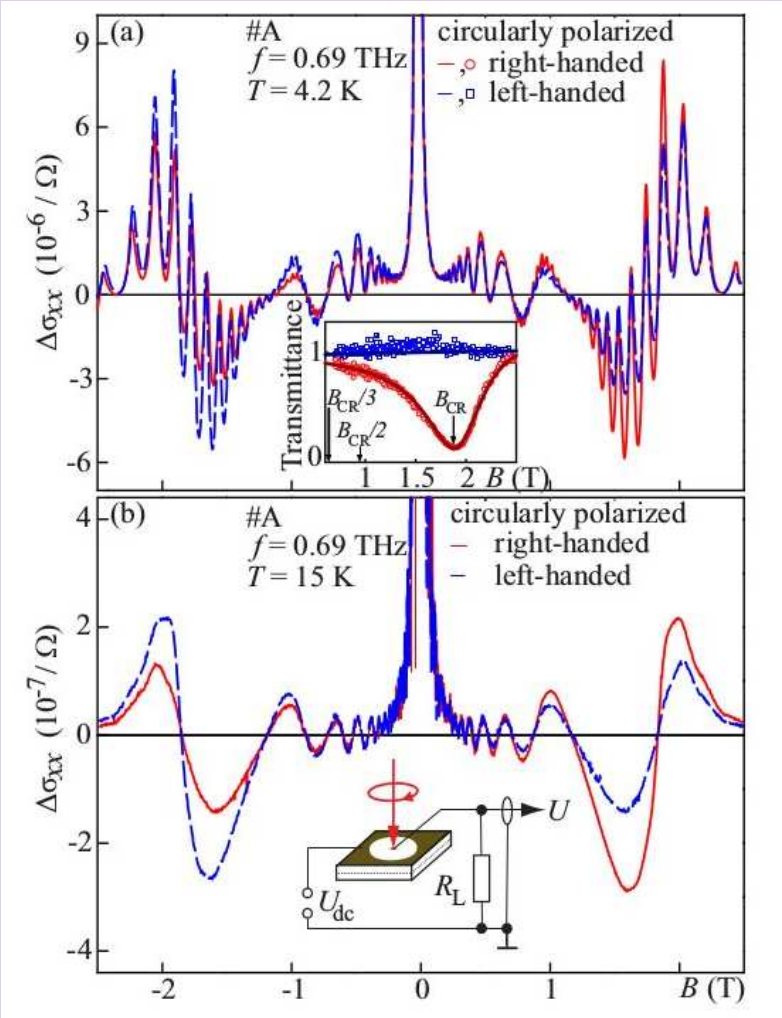
Thermoelectricity of Wigner crystal in Aubry pinned phase



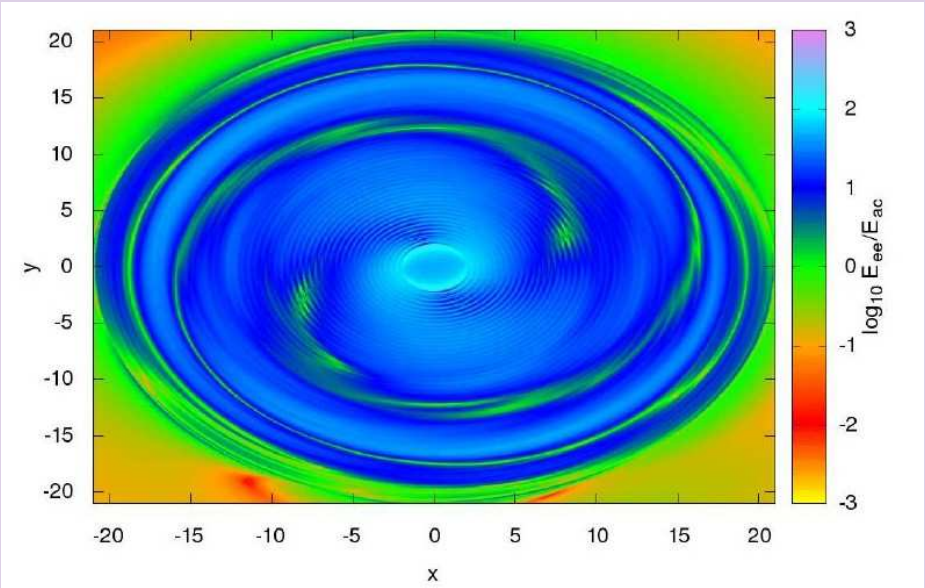


Left: Linearized approximation by the Chirikov standard map gives $K_c = 0.034(\nu/1.618)^3$ at electron density ν,
red curve is from the Chirikov standard map approximation;
Right: figure of merit ZT, maximum $ZT = 8$, in material science $ZT = 2.6$
Zhirov (BINP Novosibirsk), Lages (UTINAM Besancon), DLS (EPJD 2019) + scalable ion quantum computer in Aubry phase DS EPJD (2019)

MIRO: Problem of polarization dependence



Mani et al. Nature(2002);
Zudov, Du PRL (2003)

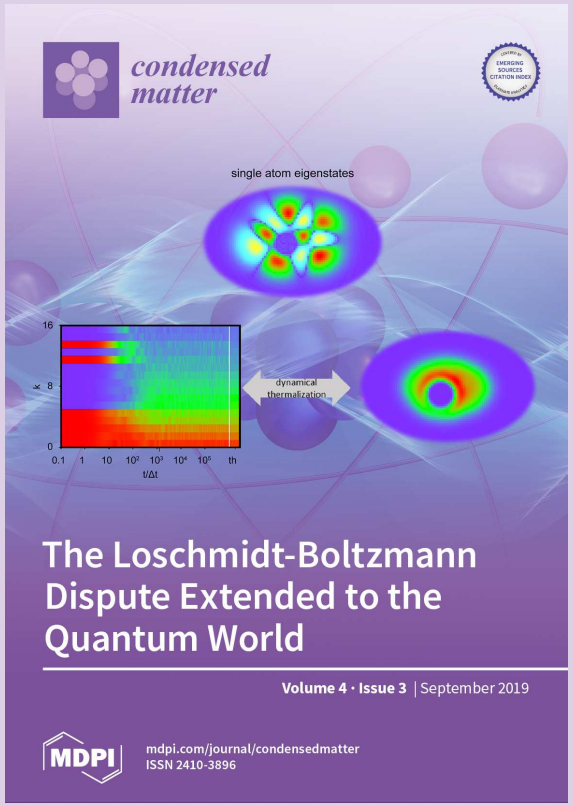


==> “polarization dependence at low harmonics is at odds with any existing theoretical description of MIRO”

Left: Ganichev-Kvon group PRB(2016); Right: A.Chepelianskii (LPS), DLS quantum theory (PRB 2018) with links to Azbel’-Kaner effect JETP (1957)

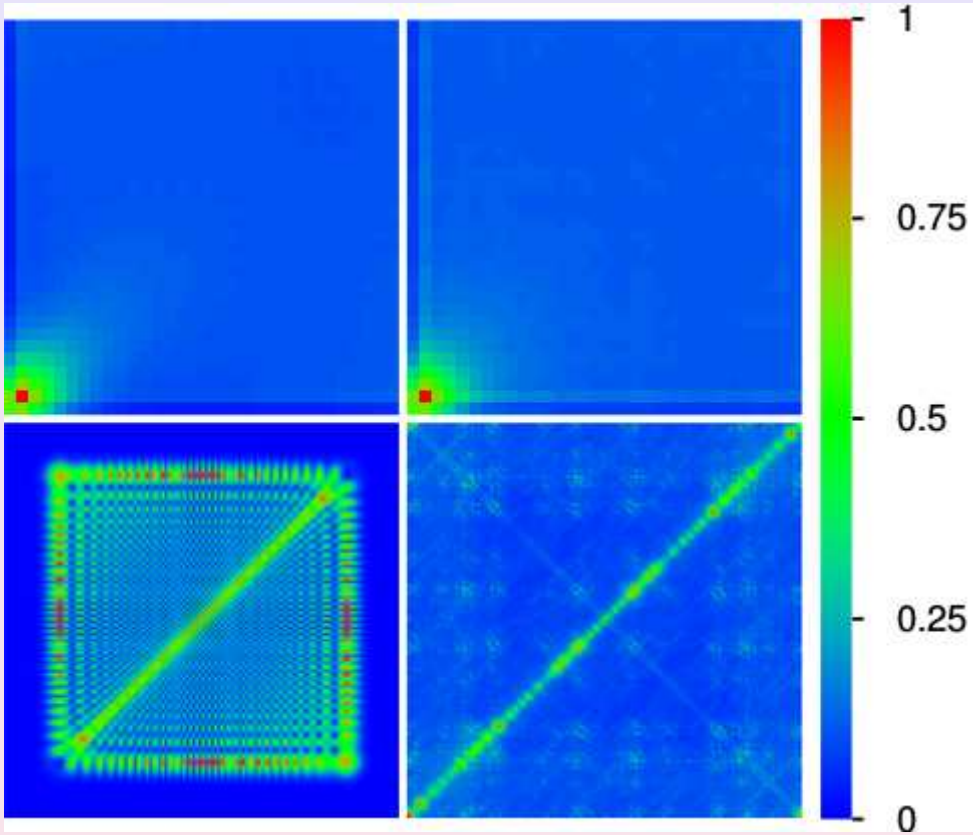
The Loschmidt-Boltzmann dispute of 1876 extended to the Quantum World

* irreversible kinetic theory from reversible equations
  (fermionic atoms in Sinai oscillator trap - Ketterle et al. (PRL 1995))



Sitzungsberichte der Akademie der Wissebschaften, Wien,
II **73**, 128 (1876); **75**, 67 (1877) → Åberg (PRL 1990)
Frahm, Ermann, DLS MDPI Cond. Mat. (2019) [+TBRIM+SYK black hole model]

Electron pairing by Coulomb repulsion in narrow band structures

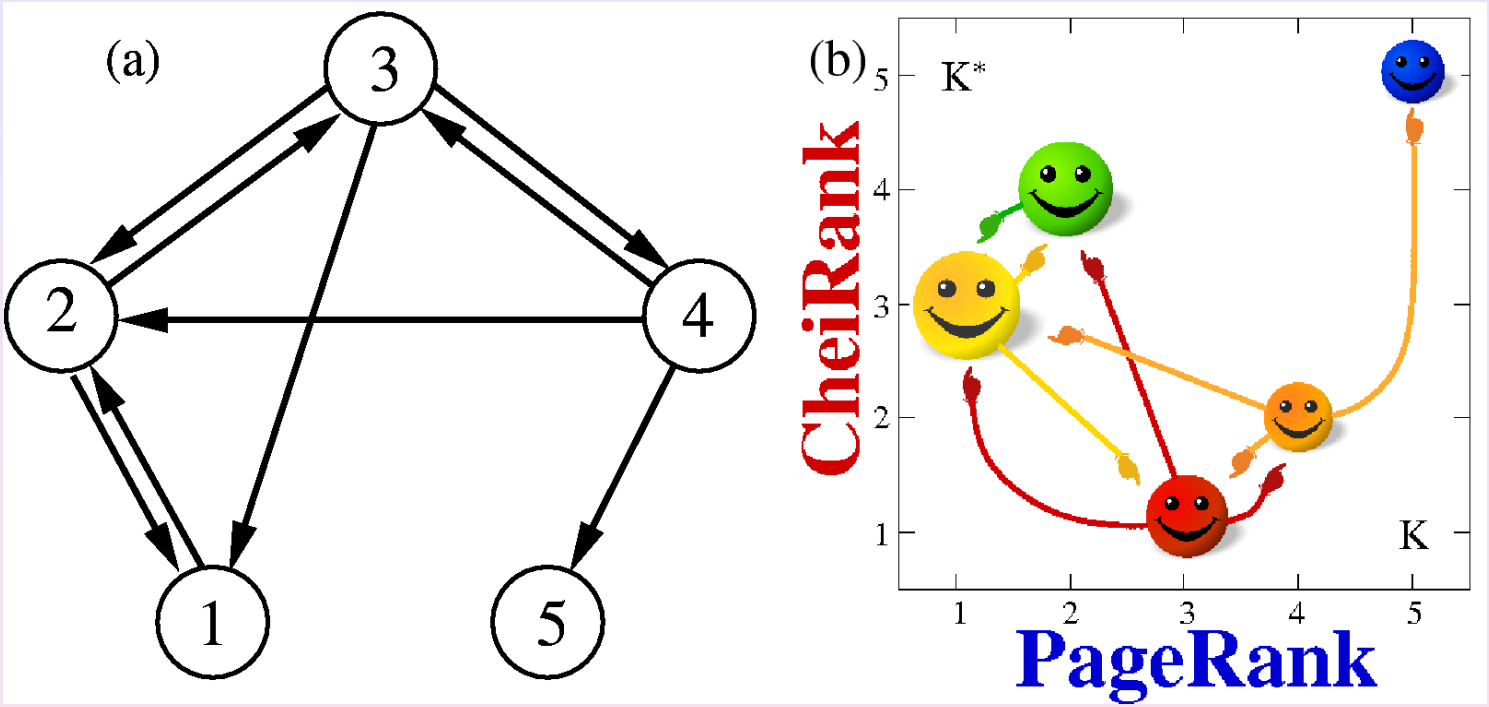


Two electrons on 2D square lattice wih hopping being unity, Coulomb intercation $U/(1+|r_1-r_2|)$; in Fig: top - probability in relative distance; bottom - projected electron probability in x, y plane; left/right: $t = 445/10^4$ time steps; density is shown by color

Frahm, DS arXiv:2002.06556[cond-mat.supr-con]

Google matrix construction rules

Markov chains (1906) and Directed networks



For a directed network with N nodes the adjacency matrix $\mathbf{A}$ is defined as $A_{ij} = 1$ if there is a link from node j to node i and $A_{ij} = 0$ otherwise. The weighted adjacency matrix is

$$S_{ij} = A_{ij} / \sum_k A_{kj}$$

In addition the elements of columns with only zeros elements are replaced by $1/N$.

Google matrix construction rules

Google Matrix and Computation of PageRank

$\mathbf{P} = \mathbf{SP} \Rightarrow \mathbf{P}$= stationary vector of $\mathbf{S}$; can be computed by iteration of $\mathbf{S}$.

To remove convergence problems:

- Replace columns of 0 (dangling nodes) by $\frac{1}{N}$:

$$S = \begin{pmatrix} 0 & 1/2 & 1/3 & 0 & 1/5 \\ 1 & 0 & 1/3 & 1/3 & 1/5 \\ 0 & 1/2 & 0 & 1/3 & 1/5 \\ 0 & 0 & 1/3 & 0 & 1/5 \\ 0 & 0 & 0 & 1/3 & 1/5 \end{pmatrix} \qquad S^* = \begin{pmatrix} 0 & 1/3 & 0 & 0 & 0 \\ 1/2 & 0 & 1/2 & 0 & 0 \\ 1/2 & 1/3 & 0 & 1 & 0 \\ 0 & 1/3 & 1/2 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

- To remove degeneracies of $\lambda = 1$, replace $\mathbf{S}$ by **Google matrix**
  $\mathbf{G} = \alpha\mathbf{S} + (1-\alpha)\frac{\mathbf{E}}{N}$; $GP = \lambda P$ => Perron-Frobenius operator
- α models a random surfer with a random jump after approximately 6 clicks (usually $\alpha = 0.85$); PageRank vector => P at $\lambda = 1$ ($\sum_j P_j = 1$).
- CheiRank vector P^*: $G^* = \alpha\mathbf{S}^* + (1-\alpha)\frac{\mathbf{E}}{N}$, $G^*P^* = P^*$
  ($\mathbf{S}^*$ with inverted link directions) $\rightarrow K - K^*$ PageRank-CheiRank index
  Chepelianskii arXiv:1003.5455 (2010) ...

Computation algorithms

* PageRank vector by power iteration:
multiplication of initial random vector by G matrix; convergence to $\lambda = 1$ eigenvector as α^t, about $t = 200$ iterations are enough for double precision convergence (all eigenvalues have $|\lambda| \leq \alpha < 1$ except $\lambda = 1$);
on average there are only about 10-20 nonzero links for each node (about 20 multiplications of vector by a line of matrix)
$\rightarrow$ small-world structure of real networks or six degrees of separation (Milgram Psychology Today (1967));
* Arnoldi algorithm: eigenvalues with largest $|\lambda|$ and related selected eigenvectors corresponding to quasi-isolated communities.
* REGOMAX Reduced Google matrix: description of interactions of subset of selected nodes in a huge network
* GPU codes for reduced Google matrix: 100 times acceleration compared to one-processor computer; collaboration with
Denis Demidov (Russian Academy of Sciences, Kazan; see https://github.com/ddemidov for GPU oriented codes)
What is the central bank of Wikipedia ?
by D.Demidov, K.M.Frahm, DS Physica A v.542, p.123199 (2020)

Google matrix of directed networks

* Wikipedia editions: EN (2009) $N = 3282257$;
24 editions Wiki2013: $N = 4212493$ EN, $N = 1532978$ DE, $N = 1352825$ FR
24 editions Wiki2017: $N = 5416537$ EN, $N = 2057898$ DE, $N = 1866546$ FR

* Entire Twitter (2009): $N = 41$millions

* Entire Phys. Rev. citation network(1893-2009): $N = 460422$

* World Trade Network (WTN) from UN COMTRADE about 50 years: $N = 227$ for all commodities; multiproduct trade with 61 products $N = 13847$; available with 5000 products and $N \approx 1 million$

* Bitcoin network transactions (beginning 2009 till April 2013): $N = 6297009$

* Linux Kernel network: $N = 285509$

* UK university networks till 2006: U Oxford, Cambridge $N \approx 200000$

* Network of protein-protein interactions for cancer: $N \approx 4000$

see L.Ermann (TANDAR Buenos Aires), K.Frahm, DLS Rev Mod Phys (2015)
http://www.quantware.ups-tlse.fr/dima/subjgoogle.html

Reduced Google matrix (REGOMAX)

A selected network of interest with $N_r \ll N$ nodes called reduced network.
Block structure of G matrix:

$$G = \begin{pmatrix} G_{rr} & G_{rs} \\ G_{sr} & G_{ss} \end{pmatrix}$$

with s index for scattering network $N_s = N - N_r$.
Reduced G_R matrix
(analogy with quantum chaotic scattering, nuclear and mesoscopic physics)

$$G_{\rm R} P_r = P_r \quad , \quad G_{\rm R} = G_{rr} + G_{rs}(\mathbf{1} - G_{ss})^{-1} G_{sr} = G_{rr} + G_{pr} + G_{qr}$$

Useful expansion

$$(\mathbf{1} - G_{ss})^{-1} \quad = \quad \mathcal{P}_c \frac{1}{1-\lambda_c} + \mathcal{Q}_c \sum_{l=0}^{\infty} \bar{G}_{ss}^{l}$$

with projector $\mathcal{P}_c = \psi_R \psi_L^T$ on eigenstate of maximal eigenvalue λ_c of G_{ss}, the complementary projector $\mathcal{Q}_c = \mathbf{1} - \mathcal{P}_c$ and $\bar{G}_{ss} = \mathcal{Q}_c G_{ss} \mathcal{Q}_c$.

K.Frahm, DLS arxiv:1602.02394 (2016);
K.Frahm, Katia Jaffres-Runser (N7-IRIT), DLS EPJB (2016)

Protein-protein interactions for cancer networks

PLOS ONE | Reduced Google matrix for directed biological networks

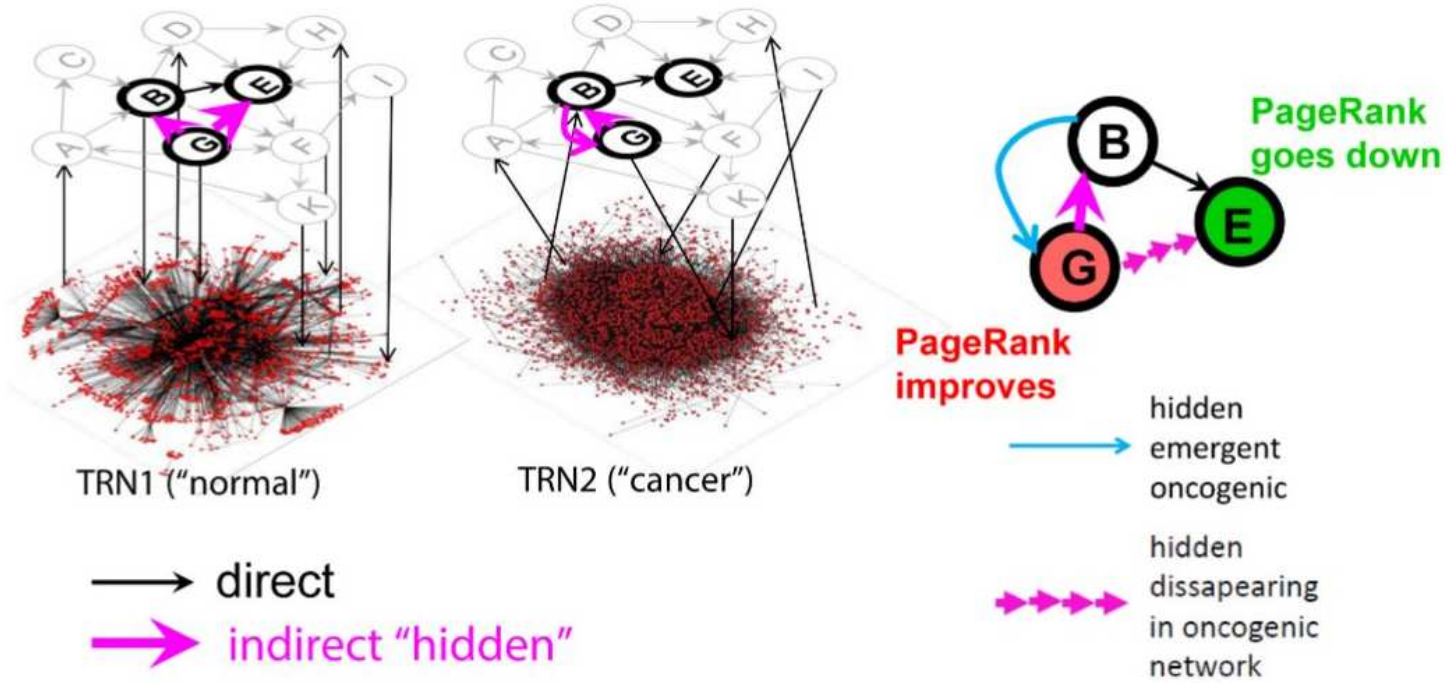
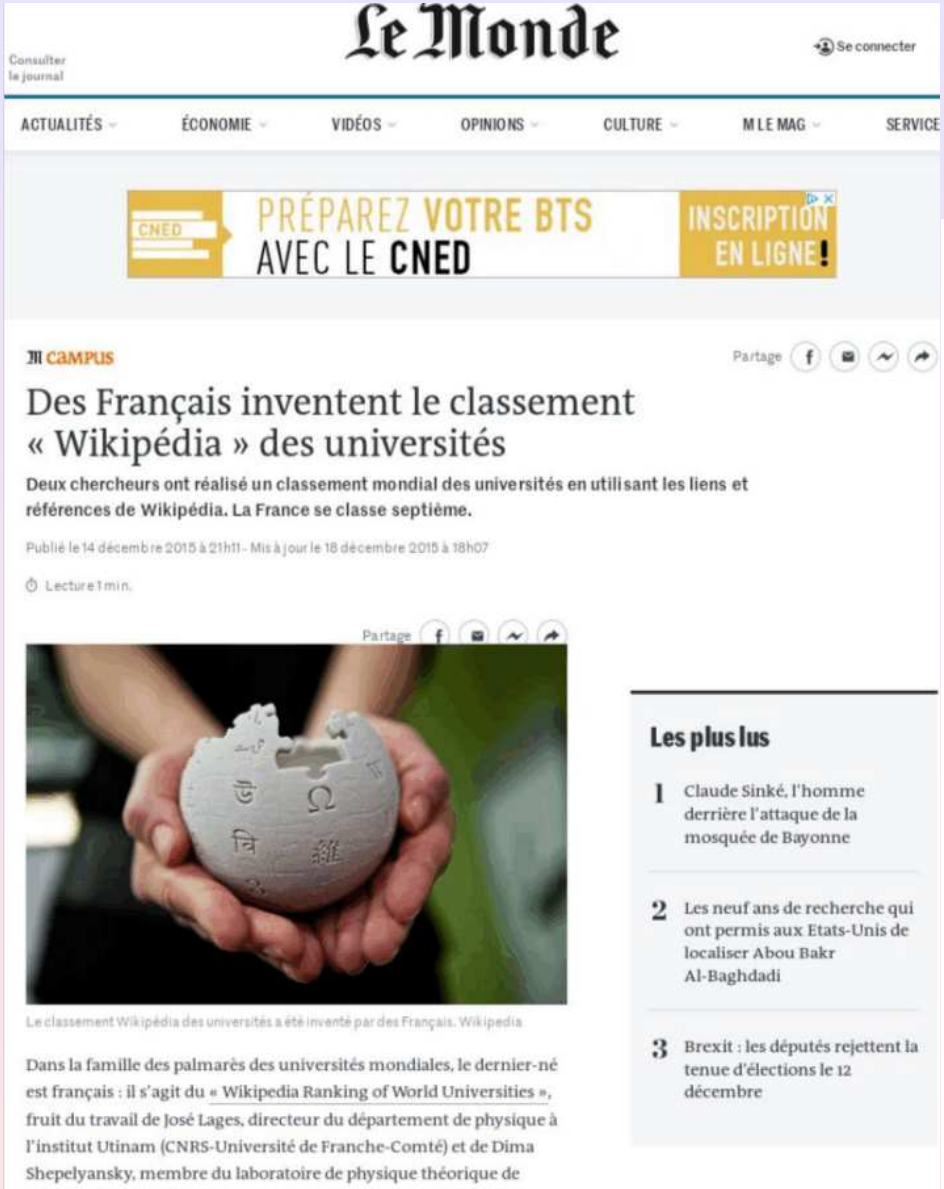


Fig 1. Using reduced Google matrix approach for inferring hidden causal relations in signaling pathways. Here the structure of the context-dependent global regulatory network is symbolically shown as consisting of two layers: the upper (nodes A-K) is the global signaling network whose structure does not depend on the context and the lower is a symbolic view of the contextual transcriptional regulatory network (TRN) whose structure can change between a "normal" and a "cancer" cell. Thick node borders denote a pathway embedded into the global signaling network. Black arrows denote direct physical interactions. Pink arrows denote inferred hidden directed regulations through the global regulatory network (both layers). In the final representation of the pathway (on the right), one can show those hidden regulations which emerge or disappear due to the changes in the TRN structure. Also, the color of the pathway nodes can show the direction of PageRank change: green corresponds to the PageRank decreased in the cancer network while red corresponds to the opposite.

https://doi.org/10.1371/journal.pone.0190812.g001

Lages, DS, Zinovyev (PLoS ONE 2018) (Besancon+LPT+Inst Curie)
Frahm, DLS + Inst Curie (PLoS Comput Biol 2020)

Wikipedia ranking of world universities (WRWU)



Le Monde

Consulter le journal

Se connecter

ACTUALITÉS ÉCONOMIE VIDÉOS OPINIONS CULTURE M LE MAG SERVICE

CAMPUS

Partage

Des Français inventent le classement « Wikipédia » des universités

Deux chercheurs ont réalisé un classement mondial des universités en utilisant les liens et références de Wikipédia. La France se classe septième.

Publié le 14 décembre 2015 à 21h11 - Mis à jour le 18 décembre 2015 à 18h07

Lecture 1 min.

Partage

Le classement Wikipédia des universités a été inventé par des Français. Wikipedia

Dans la famille des palmarès des universités mondiales, le dernier-né est français : il s'agit du « Wikipedia Ranking of World Universities », fruit du travail de José Lages, directeur du département de physique à l'institut Utinam (CNRS-Université de Franche-Comté) et de Dima Shepelyansky, membre du laboratoire de physique théorique de

Les plus lus

1 Claude Sinké, l'homme derrière l'attaque de la mosquée de Bayonne

2 Les neuf ans de recherche qui ont permis aux Etats-Unis de localiser Abou Bakr Al-Baghdadi

3 Brexit : les députés rejettent la tenue d'élections le 12 décembre

Friendship net of top 20 of FRWIKI: Harvard, Oxford, E Politech, Cambridge, ENS ...

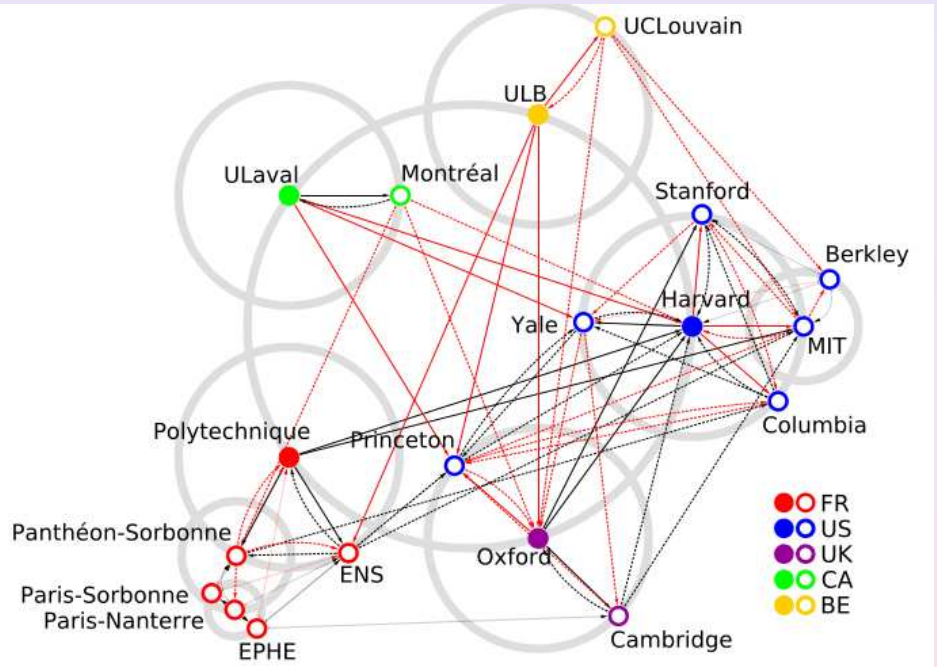
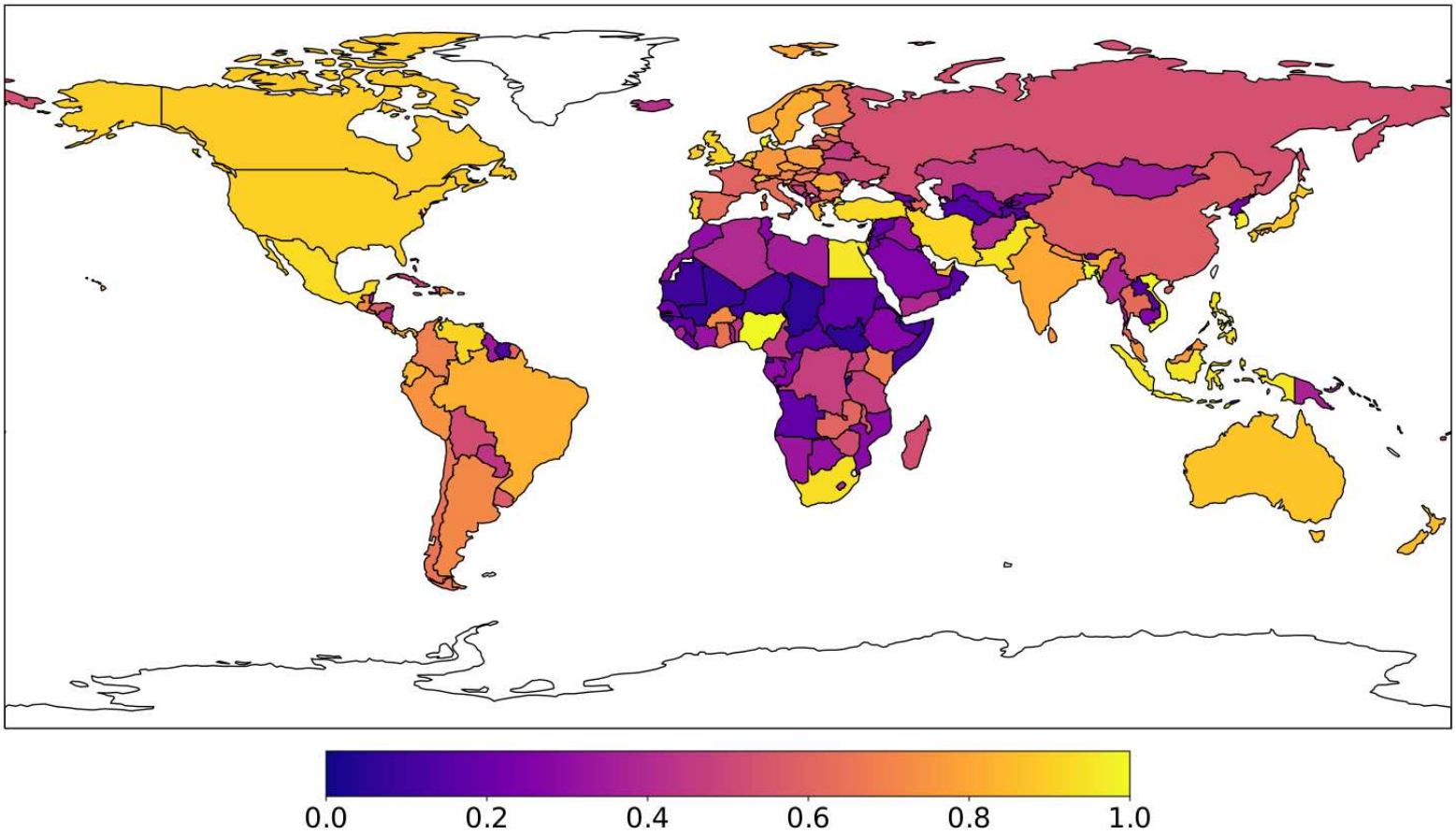


Fig. 12. Same as in Figure 10 for PageRank top 20 universities of FRWIKI2017 from Table 6. Color filled nodes are country leaders. Red links are purely hidden links, i.e., no corresponding adjacency matrix entry. We obtain 4 friendship levels (gray circles). Links originating from 1st level universities are presented by solid lines, from 2nd level by dashed lines, from 3rd level by doted lines, and from 4th level by "\" symbol lines.

Lages, Patt, DLS (EPJB 2016); Coquide, Lages, DLS (EPJB 2019)

What is the central bank of Wikipedia ?

Top asset: ICB China, China Construction Bank, Agricultural Bank of China
Top PageRank: Goldman Sachs, Citigroup, Bank of America



Sensitivity of world countries to Goldman Sachs
Demidov (RAS Kazan), Frahm, DLS (2019)

UN COMTRADE World trade network (REGOMAX)

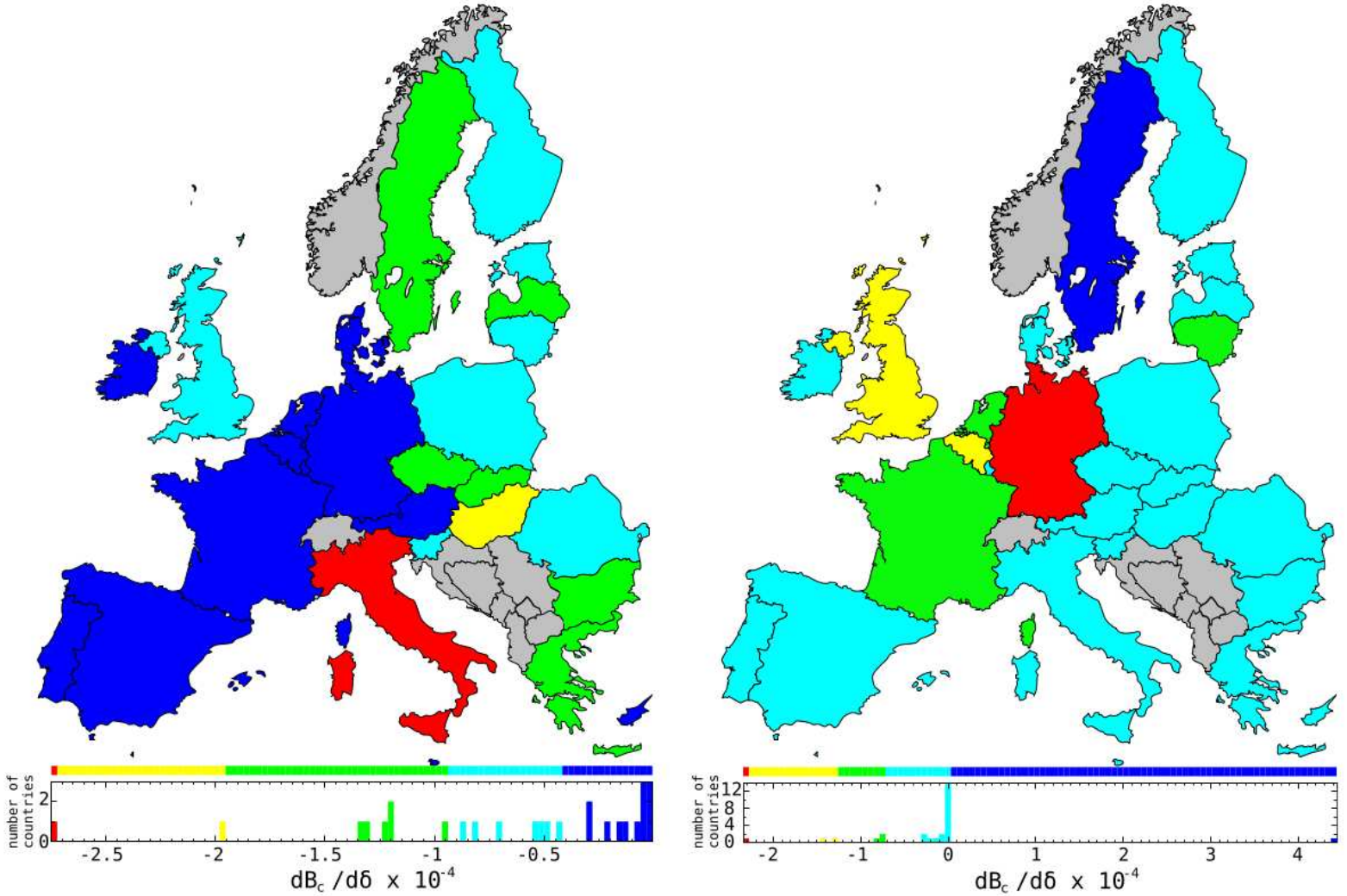


Fig. 7. EU countries balance derivative $dB_c/d\delta$ induced by an increase of gas price from Russia (left panel) and Norway (right panel) in 2016. The color categories are obtained using the Jenks natural breaks classification method [30].

EU Sensitivity to gas price of Russia (left), Norway (right) in 2016

Coquide, Ermann, Lages, DLS (EPJB 2019) (Besancon+Buenos Aires+LPT)

Publications

Ref.1 A.R.Kolovsky and D.L.Shepelyansky, "Dynamical thermalization in isolated quantum dots and black holes", Europhys. Lett. v.117, p.10003 (2017)
Ref.2 L.Ermann, E.Vergini and D.L.Shepelyansky, "Kolmogorov turbulence defeated by Anderson localization for a Bose-Einstein condensate in a Sinai-oscillator trap", Phys. Rev. Lett. v.119, p.054103 (2017)
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Ref.7 L.Ermann, K.M.Frahm and D.L.Shepelyansky, "Google matrix of Bitcoin networks", Eur. Phys. J. B v.91, p.127 (2018)

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Ref.8 S. El Zant, K.Jaffres-Runser and D.L.Shepelyansky, "Capturing the influence of geopolitical ties from Wikipedia with reduced Google matrix", PLoS ONE v.13(8), p.e0201397
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Ref.13 G.Rollin, J.Lages and D.L.Shepelyansky, "World influence of infectious diseases from Wikipedia network analysis", IEEE Access v.7, p.26073 (2019)
Ref.14 L.Ermann and D.L.Shepelyansky, "Incommensurate standard map", Phys. Rev. E v.99, p.012215 (2019)

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Ref.16 M.Y.Zakharov, D.Demidov and D.L.Shepelyansky, "Transport properties of a Wigner crystal in one- and two-dimensional asymmetric periodic potentials: Wigner crystal diode" Phys. Rev. B v.99, p.155416 (2019)
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Ref.21 D.L.Shepelyansky, "Quantum computer with cold ions in the Aubry pinned phase", Eur. Phys. J. D v.73, p.148 (2019)
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Ref.30 K.M.Frahm and D.L.Shepelyansky, "Electron pairing by Coulomb repulsion in narrow band structures", arXiv:2002.06556[cond-mat.supr-con] (2020)