"A Moveable Feast" of the Mind: Five Decades with David Pines

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Boston University

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Overriding themes

Science: Polarons, strongly correlated electron systems, superconductivity/superfluidity from BCS to nuclei to ^{4}He to High T_c to Neutron Stars

Institution Building: Center for Advanced Study (UIUC), proto-ITP, CNLS/SFI, ICAM, I2CAM

Science Diplomacy: Interactions with Russians and Chinese

Education: Frontiers of Physics, RMP, Aspen 2004 workshop, ICAM SEEs, TLS

By the Decades/Locations

Cambridge, 1969-70: a job!
Urbana, 1970-72 : CAS and instructorship
Princeton, IAS: 1972-1974 Pion condensation and neutron stars: a serious scientific overlap
Los Alamos/Santa Fe : 1974-1990: CNLS, SFI, origins of ICAM
Aspen: 1974-2017: numerous happy occasions
Urbana, redux 1992-2000: David's "boss"
Boston and Davis, 2000-2017, ICAM, Aspen, SFI

By the Decades/Locations

Cambridge, 1969-70: a job!

"In 1950, there were almost no academic jobs in Physics, so I had felt lucky to receive an offer late that summer of an Instructorship at the University of Pennsylvania.."*

In 1970 when I graduated from Cambridge there were also no jobs—like slammed door. Met DP in early 1970 in Cambridge and he went back to Urbana and clabbered together a position for me as a half-time instructor in Physics and half-time fellow in the Center for Advanced Study, which he had just recently founded.

Lesson learned: mentoring matters !

* Pines, NAS Autobiography, p. 12

Science: Polarons

Shared interest, separated in time DP (1950s), DC (1980s)

Landau sets the stage: the first polaron paper

Landau LD "Über die Bewegung der Elektronen in Kristallgitter". Phys. Z. Sowjetunion. **3**: 644–645 (1933)

Key Pines Paper: T. D. Lee, F. E. Low, and D. Pines "The Motion of Slow Electrons in a Polar Crystal,", Phys. Rev 90, 297-302 (1953)

Key DKC paper: D. K. Campbell, A. R. Bishop, and K. Fesser, "Polarons in Quasi-One Dimensional Systems," Phys. Rev. B 26, 6862 (1982)

Science: Polarons

T. D. Lee, F. E. Low, and D. Pines "The Motion of Slow Electrons in a Polar Crystal,", Phys. Rev 90, 297-302, 1953.

A variational technique is developed to investigate the low-lying energy levels of a conduction electron in a polar crystal. Because of the strong interaction between the electron and the longitudinal optical mode of the lattice vibrations, perturbation-theoretic methods are inapplicable. Our variational technique, which is closely related to the "intermediate coupling" method introduced by Tomonaga, is equivalent to a simple canonical transformation. The use of this transformation enables us to obtain the wave functions and energy levels quite simply. Because the recoil of the electron introduces a correlation between the emission of successive virtual phonons by the electron, our approximation, in which this correlation is neglected, breaks down for very strong electron-phonon coupling. The validity of our approximation is investigated and corrections are found to be small for coupling strengths occurring in typical polar crystals.

$$H=\sum_k a_k^* a_k \hbar\omega + \sum_k \{V_k a_k e^{i\mathbf{k}\cdot\mathbf{r}} + V_k^* a_k^* e^{-i\mathbf{k}\cdot\mathbf{r}}\} + p^2/2m, \quad (4)$$

where we have neglected a zero-point energy $\sum_k \frac{1}{2}\hbar\omega$, and where

$$V_k = -\frac{\hbar\omega i}{k}\left(\frac{\hbar}{2m\omega}\right)^{\frac{1}{4}}\left(\frac{4\pi\alpha}{V}\right)^{\frac{1}{2}}, \quad (5)$$

and

$$\alpha = \frac{e^2}{2\hbar c}\left(\frac{2mc^2}{\hbar\omega}\right)^{\frac{1}{2}}\left(\frac{1}{n^2}-\frac{1}{\epsilon}\right). \quad (6)$$

Science: Polarons

D. K. Campbell, A. R. Bishop, and K. Fesser, "Polarons in Quasi-One Dimensional Systems, Phys. Rev. B 26, 6862, 1982

We discuss the nature of polaron excitations in two models of current interest in the study of quasi-one-dimensional materials: the coupled electron-phonon and molecular-crystal models. Using for definiteness parameters appropriate to *trans*-$(CH)_x$, we show that, although qualitatively very similar, the two polarons differ quantitatively in many respects. We then consider the very weakly bound polaron limit and show that here the two polarons become identical. We indicate that this limit, although not applicable to *trans*-$(CH)_x$, may be relevant to other interesting quasi-one-dimensional materials.

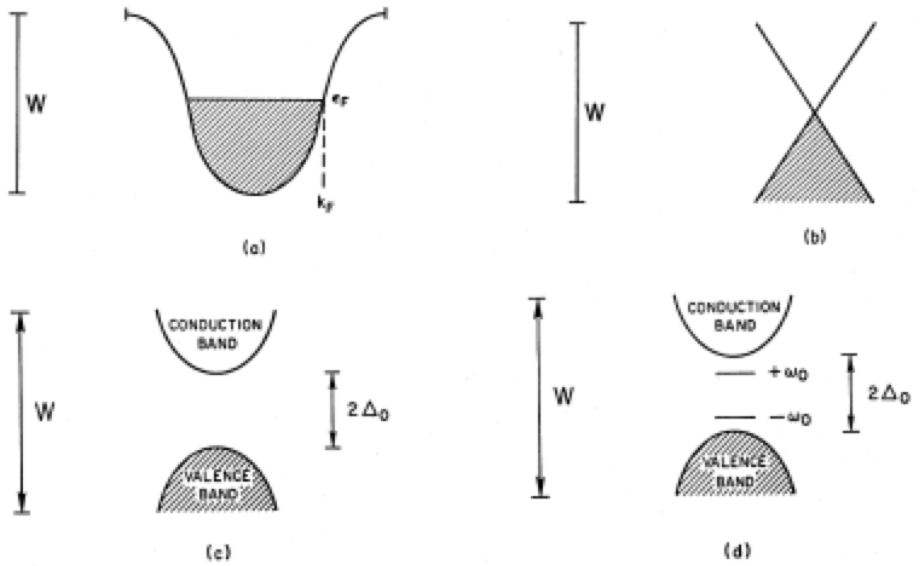


FIG. 2. Single-electron spectrum in the coupled electron-phonon Hamiltonian: (a) the lattice spectrum before the Peierls's instability, (b) the Luttinger-type spectrum obtained by expanding (a) around $\epsilon=\epsilon_F$, $k=k_F$, (c) the continuum spectrum after the Peierls's instability for constant gap parameter $\Delta=\Delta_0$; $\epsilon(k)=[(k^2v_F^2+\Delta_0^2)]^{1/2}$, and (d) the spectrum for the polaron solution. For the electron polaron the state at $(-\omega_0)$ is doubly occupied and that at $(+\omega_0)$ is singly occupied. For the hole polaron, the state at $(-\omega_0)$ is singly occupied. Possible bipolaron states are described in Refs. 21–23.

By the Decades/Locations

Urbana, 1970-72:

Half-time position at the Center for Advanced Study, founded by David in 1967

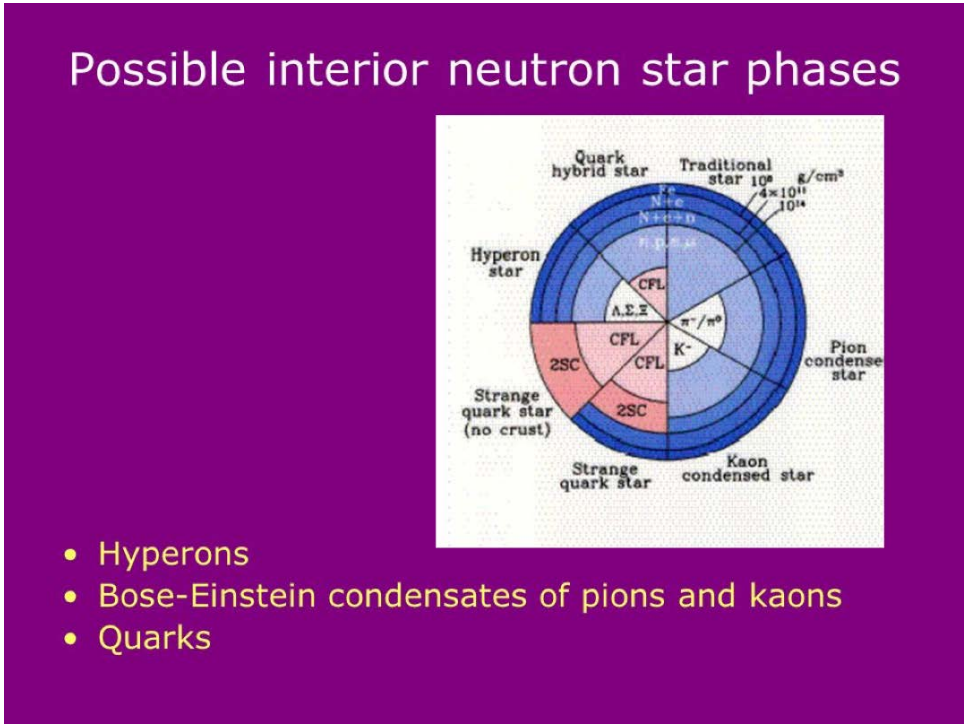
Half-time position in Department of Physics: DP working on neutron stars, DKC working on high energy theory,

Welcoming nature of parties at David and Suzy's place—drawings/paintings of Ben Shahn and Vadim Sidur

Lesson learned: collegiality matters !

By the Decades/Locations

Princeton, IAS: DP 1958-1959, DKC 1972-1974 In 1970s, common interest in neutron stars: pion condensation, star quakes, and superfluidity: a serious scientific overlap, but from a distance



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Science: Neutron Stars

Lev Landau (again!): concept of neutron stars:
"unheimliche Sterne"

"We review the history of neutron star physics in the 1930s that is related to L. Landau. According to recollections of Rosenfeld … Landau improvised the concept of neutron stars in a discussion with Bohr and Rosenfeld just after the news of the discovery of the neutron reached Copenhagen in February 1932. We present arguments that the discussion took place in March 1931, before the discovery of the neutron, and that they in fact discussed the paper written by Landau in Zurich in February 1931 but not published until February 1932… In his paper Landau mentioned the possible existence of dense stars which look like one giant nucleus; this can be regarded as an early theoretical prediction or anticipation of neutron stars, prior to the discovery of the neutron. The coincidence of the dates of the neutron's discovery and the paper's publication has led to an erroneous association of the paper with the discovery of the neutron."

Yakovlev, Haensel, Baym, and Pethick: ArXiv:1210.0682 [physics.hist-ph]

Science: Neutron Stars

Pines earliest paper on neutron stars was with Gordon Baym and Chris Pethick, "Superfluidity in Neutron Stars", Nature 224 673 (1969).

In all, David published ~33 papers on neutron stars, dealing with topics ranging from superfluidity to glitches in pulsar emission rates, to quakes in the crust, to vortex creep.

In light of their "discussion" over the mechanism of high T_c , it is amusing that many of these papers were published together with Phil Anderson (and other colleagues).

Science: Neutron Stars

Pines and Anderson collaborating !

"PINNED VORTICITY IN ROTATING SUPERFLUIDS, WITH APPLICATION TO NEUTRON STARS" PINES, D; SHAHAM, J; ALPAR, MA; ANDERSON, PW
SUPPLEMENT OF THE PROGRESS OF THEORETICAL PHYSICS 69 376-396, 1980

"THE RHEOLOGY OF NEUTRON STARS VORTEX-LINE PINNING IN THE CRUST SUPERFLUID" ANDERSON, PW ; ALPAR, MA; PINES, D; SHAHAM, J PHILOSOPHICAL MAGAZINE A-PHYSICS OF CONDENSED MATTER STRUCTURE DEFECTS AND MECHANICAL PROPERTIES 45, 227-238, 1982.

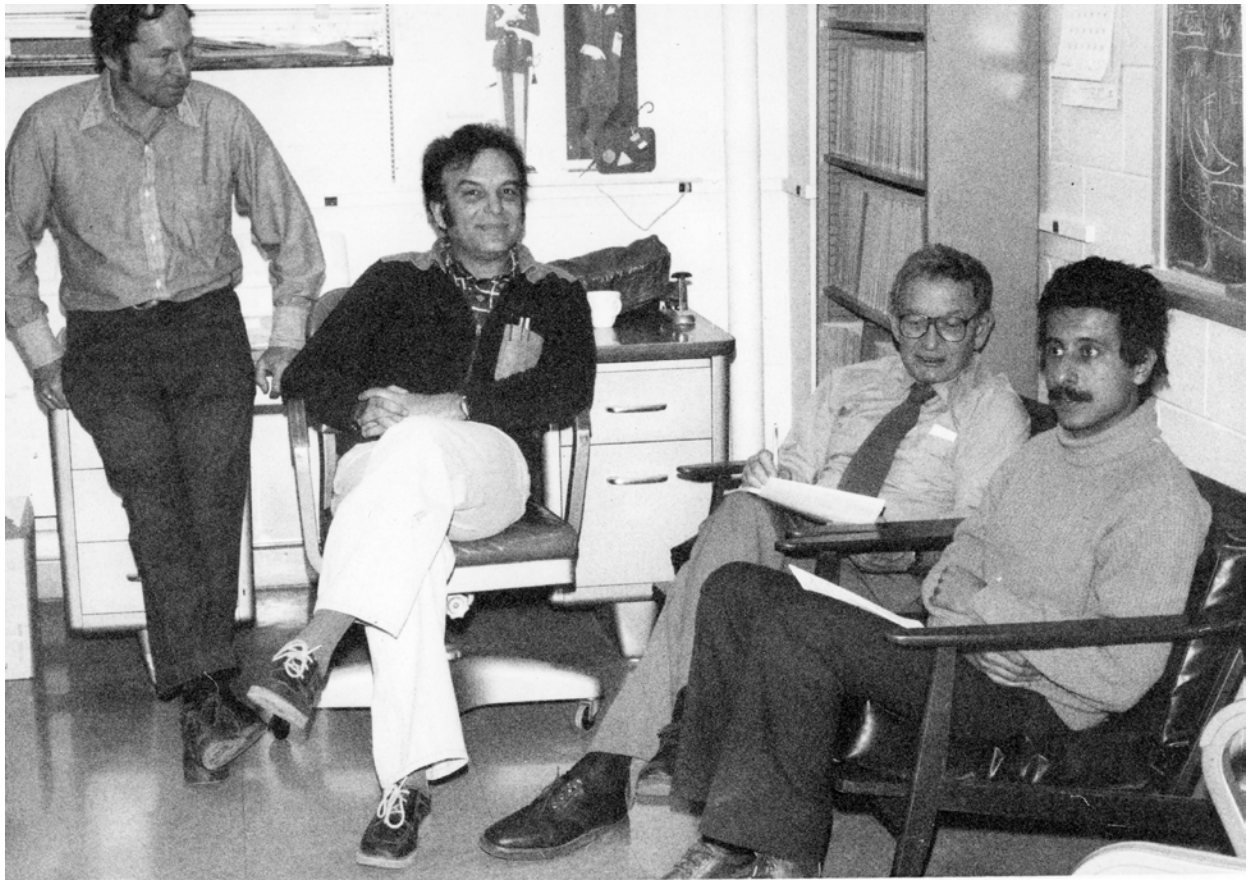
"VORTEX CREEP AND THE INTERNAL TEMPERATURE OF NEUTRON STARS .1. GENERAL-THEORY" ALPAR, MA; ANDERSON, PW; PINES, D; SHAHAM, J; ASTROPHYSICAL JOURNAL 276 325-334 1984.

"VORTEX CREEP AND THE INTERNAL TEMPERATURE OF NEUTRON STARS .2. VELA PULSAR" ALPAR, MA; ANDERSON, PW; PINES, D; SHAHAM, J, ASTROPHYSICAL JOURNAL 278 ,791-805 1984

TTN: What do you notice ?

Lesson: Friends can agree on some problems, disagree on others: it's about the physics, not the personalities.

Neutron Stars: The visual proof: David and Phil



Pines, Shaham, Anderson, Ali Alpar (Bogazici U) Neutron Star Conference, Urbana February 1981

Science: Neutron Stars

Pion Condensation in a nutshell

Basic idea of pion condensation. Fermi levels of neutrons and (few) protons in neutron star >> temperature.
What happens if chemical potential of neutrons exceeds that of protons by more than the mass of a π^- ?

In non-interacting theory can have n=> p + π^-, pions Bose condensed. But pion-nucleon interaction strongly attractive in p-wave (Δ-resonance) => pion condensate expected in non-zero momentum state, exotic superfluid/superconducting state.

Possibility suggested by several authors in 1973 by Migdal, Sawyer and Scalapino, Baym.

Science: Neutron Stars

DKC work on pion condensation.

(Led to connection to A B Migdal)

D. K. Campbell and R. F. Dashen, J. T. Manassah, "Chiral symmetry and pion condensation: I. Model-dependent results," *Phys. Rev. D* **12**, 979-1009 (1975).

D. K. Campbell, R. F. Dashen, and J. T. Manassah, "Chiral symmetry and pion condensation: II. General formalism," *Phys. Rev. D* **12** 1010-1025 (1975).

G. Baym, D. K. Campbell, R. Dashen, and J. T. Manassah, "A Simple Model Calculation of Pion Condensation in Neutron Matter," *Phys. Lett. B* **58**, 304-308 (1975).

O. E. Maxwell, G. E. Brown, D. K. Campbell, R. F. Dashen, and J. T. Manassah, "Beta Decay of Pion Condensates as a Cooling Mechanism for Neutron Stars," *Astrophys. J.* **216**, 77-85 (1977).

G. Baym and D. K. Campbell, "Chiral Symmetry and Pion Condensation," pp. 1031-1094 in Vol. III of *Mesons in Nuclei*, M. Rho and D. Wilkinson, eds., (North Holland, 1979).*

*My publications with Gordon give me a Pines # of 2

Science: Neutron Stars

Phil Anderson's work on Pion Condensation

"ARE NEUTRON STAR CORES PION CONDENSATES OR QUANTUM CRYSTALS", PALMER, RG; TOSATTI, E; ANDERSON, PW, NATURE-PHYSICAL SCIENCE 245 ,Issue 147, p. 119-120 1973.

"POSITIVELY CHARGED ISOSPIN WAVE SOFTENING AND PROTON LATTICE IN NEUTRON STARS" ANDERSON, PW; ITOH, N; ALPAR, MA; TOSATTI, E; PALMER, RG LETTERE AL NUOVO CIMENTO 12 165-170,1975.

Neutron stars very much in the news

GW170817 event observed by LIGO and Virgo detectors on August 8, 2017 also observed by non-gravitational means. Involved collapse of two neutron stars producing a "kilonova", 1000 times brighter than a normal nova and thought to be the source of most heavy elements (beyond iron) in the universe (r-process).

https://upload.wikimedia.org/wikipedia/commons/transcoded/1/17/Neutron_star_merger_animation_ending_with_kilonova_explosion.webm/Neutron_star_merger_animation_ending_with_kilonova_explosion.webm.1080p.vp9.webm

Institution Building

Urbana : 1959-1995:

David built/conceived many institutions and research efforts;

Center for Advanced Study (1967-70), Founding Director

Research Group in Neutron Stars (1969-..) with Gordon Baym, Chris Pethick, Fred Lamb, Jacob Shaham

Candidate for ITP (1978)—proto ICAM! Distributed institute, focused on Urbana but not located there (cf Piers' introduction).

High T_c group (1986)—host of UIUC colleagues,…

Lesson learned: if you build it, they will come!

Memories of Urbana in the 1970-90s

Pines, Baym, Frauenfelder, Suzy Pines, Mary Ravenhall at popular science lecture: 1980s?

Memories of Urbana in the 1970-90s

DP and Murray at UIUC "Plectics" conference in
UIUC Centennial Colloquium Series April 11 1991

Memories of Urbana in the 1970-90s

Pines, Bardeen, Slichter (Baym in second row) Loomis: 1980s?

Institution Building

Los Alamos/Santa Fe : 1973-1997:

DP (1973-1997): T-DAC (1975-1982),*
Staff Member (1999-2004, 2006-2008)
Matthias Scholar (1986)
Ulam Scholar (1996-97)
Co-Founder of Santa Fe Institute (SFI): 1982; Complex adaptive systems
Origins of ICAM (Zach Fisk)

DC (1974-1992): JRO fellow (1974-77),
Staff Member (1977-1992)
Co-Founder of Center for Nonlinear Studies (CNLS) :interdisciplinary
SFI (1984-..) Complex adaptive systems
Ulam Scholar (1998-99)

Lesson learned: if you build it, they will come!

*Typical Los Alamos TLA: DAC= Division Advisory Committee

Institution Building: Santa Fe Institute

Three Davids, Santa Fe Institute SAB meeting ~2012

Science Diplomacy: Kadya Migdal

David's role in science diplomacy will be discussed in more detail by Laura Greene so I will focus on just one aspect of these interactions and one person with whom DP and I both interacted:

Arkady (Kadya) Beynusovich Migdal

"Later that summer, in August, 1957, at a lunch in Copenhagen given by Aage Bohr, I was introduced to Spartak Beliaev, who had just arrived in Copenhagen to work with Aage. Beliaev was a student of Arkady Migdal, one of Landau's earliest and most brilliant students and collaborators…. I met Migdal ten months later, in Paris in June, 1958…… Migdal turned out to be everything Aage and Marietta had told us about him: a cheery stocky man, who looked much younger than his 47 years, spoke English quite well, and had an abundance of charm. We learned his wife taught French; we talked mostly about some of his many interests outside physics--making jewelry, beginning to be a sculptor, mountain climbing, and scuba-diving."

Pines, NAS Autobiography p. 59

Science Diplomacy: Kadya Migdal

My interactions with Kadya arose from from our shared interest in pion condensation. From Los Alamos (!) I applied for and received an invitation to visit Migdal National Academy Visiting Scientist to Soviet Unions for 3 weeks in November 1977.

Life-altering experience: 50th anniversary of revolution, contact with artists and musicians:
Vadim Sidur
Seat in special section for Soviet bigwigs at concert by Fischer-Dieskau with Richter
Tape of Bachurin in main Moscow post-office
Gift of small metal icon: possible detection in luggage at airport?

DKC hosts Migdal and Belyaev in Los Alamos in 1978:
Trip to Grand Canyon; restaurant on north rim: steak to feed a Russian family for a week; Betatakin, 'howdie,"; flying through Grand Canyon, Beliaev taking photos, Migdal just admiring.

Science Diplomacy: Kadya Migdal

Pines, Migdal, Henrik Bohr, Baym, Urbana,
November 29, 1990

Education

David's role in enhancing education in physics and science in general spanned most of his career:

Frontiers of Physics, founding editor, 1961-1999: crucial to bring latest developments to young researchers

Reviews of Modern Physics, 1973-1996

Aspen 2004 workshop, stimulated DP's interest in bringing science to the public

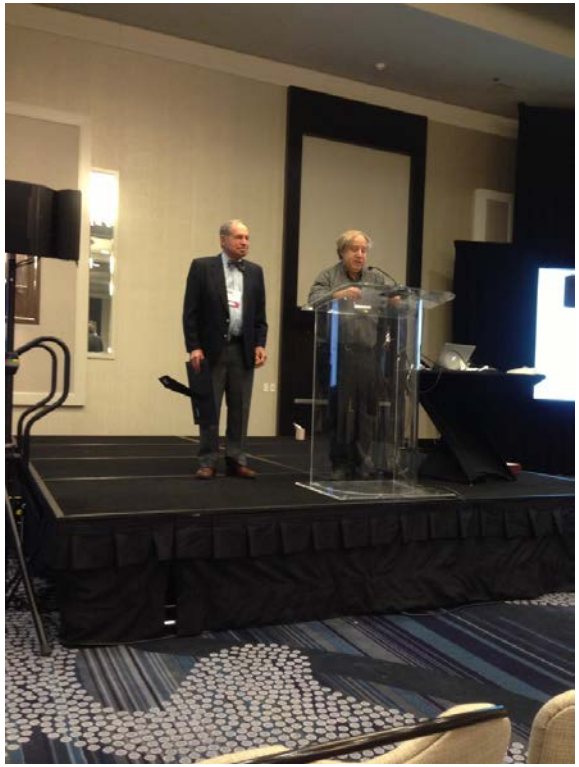
Global Partnership of Scientists Engaged in Education, Founding Co-Chair, 2009-…

ICAM's "Science, Education, and Engagement" (SEEs) initiatives

Founding Co-Chair, Think Like A Scientist Initiative, 2016-…

J. D. Jackson Award of the AAPT (2013)

Education



DP receives the 2013 J. D. Jackson Award from the AAPT

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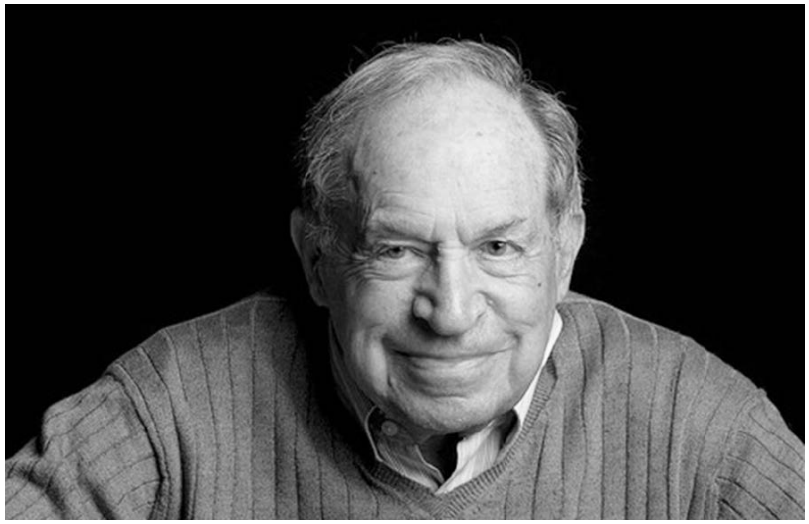

Thanks to David for all the happy memories, and thank you all for your attention !

Finis!