

Dario DiFrancesco

Curriculum vitae

Personal

Born: February 10, 1948 in Milano, Italy

Citizenship: Italian

Marital status: married, three sons

Work address: Department of Biosciences, The PaceLab, University of Milano, via Celoria 26, 20133 Milano, Italy

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Education

Università degli Studi di Milano: Doctoral Degree, 1973 (PhD equiv. Summa Cum Laude Physiology/ Biophysics)

The Physiological Laboratory, Cambridge, UK: Postdoc (Cardiac Electrophysiology)

University Laboratory of Physiology, Oxford, UK: Postdoc (Cardiac Electrophysiology)

Research positions and Academic appointments

9/73- 12/74: Teaching and research fellowship, Institute of General Physiology, Univ. Milano.

1/75- 12/80: Research Assistant, as above

9/76- 3/77: Postdoctoral fellow in Cambridge, The Physiological Laboratory (R.D. Keynes)

4/77- 12/78: Postdoc in Cardiac Electrophysiology in Oxford, The Lab. of Physiology (D. Noble).

1/81- 6/86: Assistant Professor, Dept. of General Physiology and Biochemistry, Univ. Milano.

6/86- 10/2018: Professor of Physiology, Dept. of General Physiology and Biochemistry, then Dept. of Biosciences, Univ. Milano

10/99-present: lecturer of Physiology at Vita-Salute Univ., San Raffaele Hospital, Milano

11/2018-present: Emeritus Professor, University of Milano

Primary areas of research interest

-Electrophysiology of cardiac tissue and cells

-Ionic currents and rhythmic activity in heart

-The pacemaker "funny" channel and control of heart rate

-HCN channelopathies and cardiac arrhythmias

-Pharmacology of ion channel block by drugs

-Neuronal HCN channels and neuronal channelopathies

-Cardiac stem cells

Honors and awards

1. -Recipient Accademia dei Lincei- Royal Society award 9/1976- 8/1977 (Cambridge-Oxford)

2. -Recipient Wellcome Trust award Research Grants 9/1977- 7/1979 (Oxford)

3. -Recipient Wallace O. Fenn Memorial Fund award for XXVIII IUPS Congress 1980 (Budapest)

4. -Recipient Wallace O. Fenn Memorial Fund award for XXIX IUPS Congress 1983 (Sidney)

5. -Member of the "Academia Europaea" since 1992

6. -International Prize of Physiology "Professeur Pierre Rijlant" Academic Foundation, awarded by the Royal Academy of Medicine of Belgium, 1994

7. -Lectio Magistralis Annual Congress Italian Soc. of Physiology, 1994

8. -League of European Research Universities mention for L.E.R.U. Research Breakthroughs

- 2006 as representative of best research in the University of Milano
9. - Grand Prix scientifique 2008, Fondation Lefoulon-Delalande- Institut de France, pour les "très remarquables travaux de recherche qui ont conduit à la découverte des canaux ioniques impliqués dans la régulation du rythme cardiaque" http://le foulon-delalande.institut-de-france.fr/historique-0#9_le_grand_prix_scientifique_2008
 10. -Lectio Magistralis Faculty of Science Univ. Milan 2008
 11. -Lectio Magistralis and Prize "Control of cardiac rate by "funny" channels in health and disease" Symp. "Translation in Cardiomyopathies: from genes to therapy" Padova 2009
 12. -H.C. Burger Award Lecture "The history of the discovery of funny channels" 23rd Cong. Europ. Soc. Noninvasive Preventive Cardiol. "Cardiovascular Medicine in the Era of Advanced Technology", Brescia 2009
 13. -Member of the "Istituto Lombardo- Accademia di Scienze e Lettere" since 2013
 14. -Lectio Magistralis Annual Congress Italian Soc. of Physiology, 2013
 15. -2014 Magnes Lecture Prize, Israel Society of Physiology and Pharmacology, Jerusalem January 2015
 16. -2015 Emeritus Membership of the American Physiological Society
 17. -2015 Royal Society Philosophical Transactions 350th anniversary, paper selected among the 33 most important papers since 1665: DiFrancesco & Noble (1985) Phil Trans Roy Soc Lond B 353-398; selection includes Newton, Maxwell, Joule, Faraday, Turing, Medawar, Marr etc See <https://royalsociety.org/journals/publishing-activities/publishing350/history-philosophical-transactions/>
<https://royalsocietypublishing.org/toc/rstb/370/1666>
<https://doi.org/10.1098/rstb.2014.0316>
<https://blogs.royalsociety.org/publishing/a-conversation-with-dario-difrancesco-and-denis-noble>
 18. -2017 Carmeliet-Coraboeuf-Weidmann Prize Lecture at 41st EWGCCE Congress, Vienna
 19. -2017 Fellow Membership Physiological Society UK
 20. -2019 Emeritus Professor, University of Milano
 21. -2021 Nominated International Union of Physiological Sciences (IUPS) Academy Fellow
 22. -2021 Special Issue of Progress in Biophysics and Molecular Biology dedicated to the career of Dario DiFrancesco "1979-2019: a 'Funny' journey lasting 40 years, the multiple roles of f/HCN channels" <https://www.sciencedirect.com/science/journal/00796107/166/supp/C>
 23. -Consulted annually by the Nobel Prize in Physiology or Medicine Committee since 1997

Extra-mural grants (selected)

- CNR International Research Grant (Milano- Oxford) 1982/86, 1987-89, 1990-93
- CNR Research Grant 1989-90
- MDA Basic Research Grant 1985/87
- NIH Research Grant 1987/1989
- CNR Special Project 1991-1992 Italian Coordinator
- UE Human Capital and Mobility grant 1995 through 1997
- Telethon Grant (1998/2001)
- NATO exchange grant 1998-1999 (Columbia University)
- Servier International 1999-2000; 2002-2003; 2005-2006, 2007-2009, 2013-2016
- MIUR FISR CNR Special Projects Functional Genomics 2003-2005
- FIRB Neurobiology 2003-2007
- FIRB Post- genomics 2004-2007
- FIRB New biological therapies for myocardial infarction 2005-2010
- CARIPO Biological pacemaker 2005-2007; ACROSS-cArdiac paCemakeR ageing: cellular and molecular basis 2015-2018 (PI); 2015-2018 Partner in two more CARIPO grants.
- UE "Normacor" 2006-2009

- MURST Cofin-PRIN (1997 through to 2016) including:
Cofin 1999; Cofin 2000; Cofin 2001; Cofin 2002; Cofin 2003; PRIN 2004; PRIN 2006; PRIN 2008; PRIN 2010
- Le Ren Tang Pharmaceutical 2014-2016 and 2015-2017
- Leducq Foundation Transatlantic Network of Excellence Grant "Fighting Against Sinus Node Dysfunction And Associated Arrhythmias" (FANTASY)

Scientific Societies

- Società Italiana di Fisiologia, 1973-
- Soc. Italiana di Biofisica, 1984-1989
- ABCD, 1987-2000
- The Physiological Society (UK) 1983-
- American Physiological Society (USA) from 1985, Emeritus Membership from 2015
- Biophysical Society (USA), 1999-
- Society for Neuroscience (USA), 2011-

Editorial and Committee Experience, Consultancies

- Ad hoc reviewer for all major international journals.
- Editorial Boards:
 - Journal of Cardiovascular Electrophysiology, 1992-2000
 - News In Physiological Sciences (NIPS), 1995-2002
 - Journal of Cardiovascular Pharmacology, 1996-2000
 - British Journal of Pharmacology, 2003-2007
 - Frontiers in Cardiac Electrophysiology, 2011-
- National Group Coordinator of Special Committee Grant Project on "Ionic Channels: functions and control mechanisms" 1991-93
- Commissaire de thèse de troisième cycle: Docteur Guy Champigny, Université de Poitiers, 6/1987
- Commissaire de thèse de troisième cycle: Docteur Patrick Bois, Université de Poitiers 12/1989
- Commissaire de thèse de troisième cycle: Docteur Jerome Petit-Jacques, Université de Poitiers 1/1993
- Consultant, N.I.H. Program Project Grant: Ira S. Cohen, State University of New York, Stony Brook, N.Y., 1988-92
- Grant reviewer NATO research project 1/1989
- Consultant, N.I.H. Program Project Grant: Michael Rosen, Columbia Univ., New York, 1993-98 and further renewals until today
- Grant reviewer NATO research project 1/1994
- Commissaire de thèse de troisième cycle: Docteur Jocelin Bescond, Univ de Poitiers 12/1996
- Grant reviewer Human Frontiers 12/1996
- Commissaire de thèse de troisième cycle: Docteur Barbara Renaudon, Univ de Poitiers 12/1997
- Grant reviewer NATO research project 9/1997
- Expert européen évaluation Unité INSERM U 446 (Rodolphe Fishmeister) Université de Paris Sud, Châtenay-Malabry, 9/1999
- Grant reviewer Human Frontiers 1/2003
- Grant reviewer for Italian Ministry of University and Research and other national and international granting bodies
- Commissaire de thèse de Doctorat Marie Curie: Docteur Angelo Torrente, Université de Montpellier 07/2011
- Grant reviewer for Fondation de Recherche Médicale 7/2011
- Examiner D. Phil. thesis Dr Michael A. Colman, Univ. Manchester 12/2012
- Member Selection Committee for Associate Professor competition Univ. Lleida, Catalonia, Spain 14-16/2/2018

Summary of early training and research experience

- 9/73 – 7/76 Teaching and research Fellow, then Research Assistant, Ist. Fisiol Gen, Un. Milano.
- 7/76 - 3/79: PostDoc at The Physiological Laboratory, Cambridge, U.K. and then at the Laboratory of Physiology, Oxford, U.K. (Dr Denis Noble)
- 3/79 - 12/80: Wellcome Trust Fellowship at Oxford Un. Lab. of Physiology.
- Brief periods spent in various Univ. laboratories of Physiology (Homburg/Saar, Paris XI, Tours).
- 3/79 - 12/80: Research Assistant, Ist. di Fisiologia e Biochimica Generali, Un. Milano.
- 1/81 - 6/86: Assistant Professor, Dept. of General Physiology and Biochemistry, Univ. Milano.
- 6/86 – 10/2018: Full Professor, Dipartimento di Fisiologia e Biochimica Generali, then Dipartimento di Bioscienze, Univ. Milano.
- 6/86 - 8/86, 6/88 - 8/88, 6/90 - 8/90: Visiting Professor, SUNY at Stony Brook, NY
- 1990-1996 Periodical visiting scientist and consultant, Dept. Pharmacol. Columbia Univ., N.Y.

Bibliometrics

- Over 200 full articles/reviews/book chapters; about 400 publications listed by Google Scholar; H-index: 76; citations: 21523 (Google Scholar 12/2021).
- The Google Scholar profile is public: <http://scholar.google.it/citations?user=BjMvgjYAAAAJ>
- ORCID 0000-0002-7322-1790

Invited presentations/congresses/named lectures etca: over 220 invitations worldwide

Press

Selected press articles, interviews, citations, video interviews and other material available on the web page <http://pacelab.it>

Research mentoring records

In the course of almost 4 decades, Dario DiFrancesco's lab has mentored and hosted a large number of students, postdocs, visitors many of whom have made a career in Physiology and are now established academics/researchers in worldwide locations. Here is a selected list:

- Damir Janigro, Dept. Neurosurgery/NB20, Cleveland Clinic; 9500 Euclid Av., Cleveland, Ohio 44195 (up to 2014);
- Antonio Malgaroli, Vita-Salute University, San Raffaele Hospital, Milano;
- Sergio Visentin, Istituto Superiore di Sanità, Dept. Cell Biology and Neuroscience, Rome;
- Michele Mazzanti, Dept. Biosciences, Univ. Milano, via Celoria 26, 20133 Milano;
- Richard B. Robinson, Dept. Pharmacology Columbia Univ., New York;
- Patrick Bois, IPBC, UMR 6187, CNRS, Université de Poitiers, Poitiers, France;
- Eric Accili, Dept of Cellular and Physiological Sciences, Un. British Columbia, Vancouver, British Columbia, Canada;
- Antonio Zaza, Dept Biotechnology & Biosciences, Univ. Milano-Bicocca;
- Sonia Gasparini, Louisiana State University School of Medicine, Neuroscience Center of Excellence, 2020 Gravier Street, New Orleans;
- Matteo Mangoni, Institute of Functional Genomics, Cardioprotection team-LabEx ICST, Dept Physiology, CNRS UMR 5203, Inserm U661, Univ Montpellier 1 and 2, Montpellier, France
- Gianmaria Maccaferri, Northwestern Univ. Feinberg School of Medicine, NU Inst Neuroscience, Chicago;
- Mirko Baruscotti, Dept. Biosciences, Univ. Milano, via Celoria 26, 20133 Milano;
- Raimondo D'Ambrosio, Department of Neurological Surgery and Regional Epilepsy Center, Univ. of Washington, Seattle
- Carlo Viscomi, MRC-Mitochondrial Biology Unit, University of Cambridge, UK.
- Anna Moroni, Dept. Biosciences and IBF-CNR, Univ. Milano, via Celoria 26, 20133 Milano;
- Claudia Altomare, Cellular and Molecular Cardiology Laboratory, Cardiocentro Ticino

Foundation and Swiss Institute for Regenerative Medicine

-Andrea Barbuti, Dept. Biosciences, Univ. Milano, via Celoria 26, 20133 Milano;

-Jocelyn Bescond, Signalisation et Transports Ioniques Membranaires, Univ. Poitiers, France

-Annalisa Bucchi, Dept. Biosciences, Univ. Milano, via Celoria 26, 20133 Milano.

Invited presentations, named lectures etca

1977	Dec	-London UCL Phys. Soc. meeting (abstract DiFrancesco McNaughton) -Leuven, speaker 1st meeting EWGCCE
1978	May May May July	-Bonn, seminar (O. Hauswirth) -Oxford, seminar (K depletion) -London UCL Phys. Soc. meeting (abstract DiFrancesco Ohba) -Cambridge Phys. Soc. meeting (abstract DiFrancesco Eisner Lederer)
1979	Feb Feb Nov	-Paris XI Orsay (E. Coraboeuf) -Oxford, Lunch Club Seminar (work in Homburg/Saar, IK current) -Homburg/Saar Leuven, speaker 3rd meeting EWGCCE
1980	March April June July Oct Oct Oct	-London UCL Phys. Soc. meeting (abstracts DiFrancesco + DiFrancesco & Noble) -Paris XI Orsay seminar (Edouard Coraboeuf) -Oxford Phys. Soc. meeting (abstract Brown DiFrancesco Kimura Noble: V clamp SAN) -Budapest, Inv. Lecturer XXVIII IUPS Congress -Cambridge Phys. Soc. meeting (abstracts DiFrancesco + DiFrancesco & Noble) -Berne, speaker 4th meeting EWGCCE -Amsterdam, invited speaker Symposium: Cardiac Rate and Rhythm
1981	March March April April July Oct	-London UCL Phys. Soc. meeting (317: abstract Brown DiFrancesco Kimura Noble: Cs on SAN If) -Lyon seminar (Oger Rougier, Carlos Ojeda) -Berne Phys. Soc. meeting (abstract DiFrancesco Hart Noble Shimoni: Ito and If) -Abano Terme, Fidia Res. Lab. (A. Gorio) -Oxford Phys. Soc. meeting (320: abstract DiFrancesco: Cs; DiFrancesco Noble: model) -Maastricht (5th EWGCCE cong: abstract DiF. Block activation If)
1982	Feb March	-Firenze (A. Mugelli) -Ferrara (E. Wanke)
1983	Jan June Sept	-Geneve, Centre Med. Univ. (D. Bertrand, C. Bader) -Abano Terme, Fidia Res. Lab. (M. Prosdocimi) -Sidney, Invited Lecturer XXIX IUPS Congress
1984	March July Sept Sept Sept Sept Sept	-Clermont-Ferrand (Merck-Sharp & Dhome-Chibret) -Tours (D. Garnier) -Oklahoma City, Inv. Lecturer Symp. Int. Soc Heart Research (R. Lazzara) -Atlanta (L. DeFelice) -Baltimore (J. Lederer, T. Lakatta) -Stony Brook (I. Cohen) -New York, Columbia University (M. Rosen)
1985	Jan March Sept	-Napoli (T. De Leo) -Torino (E. Meda) -Pisa, Inv. Speaker SIF
1986	Aug Aug Oct	-Banff, Speaker Sat. Symposium IUPS Congress -New York, Columbia Univ -Vienna, Inv. Lecturer Symp. Boehringer Ingelheim
1987	May May June June Oct	-Rotterdam, Lecturer Symp. Pure Bradycardic Agents -Milano, CNR -Padova, (S. Luciani) -Poitiers, Committee Board Thesis Guy Champigny -San Diego, Inv. Lecturer Congress APS

1988	Apr Apr Oct Oct Oct Dic	-Okazaki, Chairman Symp. US-Japan seminar -Tokio, Inv. Lecturer International Symposium Basic Mechanisms of Arrhythmias (H. Irisawa) -Padova, Inv. Lecturer Congress SIB -Spoleto, Inv. Lecturer Congress ABCD -Pasadena, (H. Lester) -London, Inv. Co-chairman, British Heart Foundation
1989	March May Sept Oct Dec	-Pavia, Conference Dottorato Fisiologia (Prof. Rindi) -Ann Arbor, Inv. Speaker Int. Soc. Heart Research -Homburg/Saar, Chairman Symp to honor W. Trautwein -Roma, Inv. Speaker Soc. Ital. Cardiologia -Poitiers, Committee Board thesis Patrick Bois
1990	Feb May May May July Aug Sept Sept Sept Oct	-Frankfurt, Inv. Speaker Symp. A.Thomae -New York, Columbia Univ. -Chicago, Inv. Speaker Symp. Ion channels heart and vasc. system (H. Fozzard) -Houston (A.M. Brown) -Farmington (A. Pappano) -New London, Inv. Speaker Gordon Conference Ionic Channels (H. Lester) -Firenze, Inv. Lecturer III Congr. Cell Biol. -Perugia, Inv. Speaker Congress SIF -Firenze, Inv. Speaker XVII Int. Congr. Electrocardiology -Islamorada, Florida, Inv. Speaker Hoffman Symp. (M. Rosen)
1991	April May July July Oct Dec	-Il Ciocco, Inv. Speaker NATO Workshop (M. Morad) -Roma, Un. Tor Vergata (S. Morante) -Prague, Inv. Speaker Regional Meeting IUPS (C. Hartzell) -Oxford, Inv. Speaker Symp. Cardiac Background Currents (D. Noble) -Erice, Inv. Lecturer Int. School Bioelectrochemistry -Milano, Inv. Lecturer Scuola Soc. It. Neuroscienze
1992	Feb March April May July Sept Sept Oct Nov Dec	-Pisa, (L. Maffei) -Seattle, WA (B. Hille, W. Crill) -San Diego, CA (K. Chien) -Padova, (S. Schiaffino) -Madrid, Inv. Speaker X Int. Congr. Cell Biology -Ferrara, Inv. Speaker meeting EWGCE -Naples, Inv. Speaker Nat. Congr. Pharmacology -Antwerpen (PP. van Bogaert) -Bologna (C. Rapisarda) -Vienna Inv. Lecturer Symposium Boehringer Ingelheim
1993	Jan Aug Aug Sept Oct	-Poitiers, Committee Board Thesis Jerome Petit-Jacques -Glasgow, Inv. Speaker XXXII IUPS Congress -Keystone, Colorado, Inv. Lecturer Symp. Cardiac Electrophysiology (Medtronic) -Milano, Inv. Speaker ABCD Congress -Poitiers, Inv. Lecturer "E. Coraboeuf Jubilee"
1994	March June July Sept Sept	-Firenze, Lettura Magistrale Annuale Soc. Ital. Fisiologia -Montpellier (Sanofi Recherche) -Trento (R. Antolini) -Milano, DiBit (Neurobiology Course Open Univ.) -Palermo, Invited Speaker Congress SIBPA
1995	April June	-Versailles, Inv. Speaker Workshop on Bradycardic Agents and Cardiac Arrhythmias (Servier) -Trieste, SISSA (E. Cherubini)

	Sept Oct Oct Dec	-Leuven, Symposium to honor E. Carmeliet -Bruxelles, Lecture for <i>Prof. Pierre Rijlant Prize</i> at Royal Academy of Medicine -London, King's Coll, Symposium on Cyclic-nucleotide gated channels -New York, Columbia Un. (R. Robinson)
1996	June Nov	-Banff, Inv. Speaker Symp. in honour of Denis Noble -Banff, Inv. Speaker Conference AV node
1997	Jan June July	-Nice-Sophia Antipolis (M. Lazdunski) -Erice, Symposium Synaptic Communication (E. Cherubini) -St. Petersburg, Inv. speaker Symposium Cell Oscillators (A. Noma)
1998	Oct	-Jülich (B. Kaupp)
1999	March April Sept Sept Sept Sept	-Miami, 2 nd Workshop Cardiac rate inhibitors. (Servier) -Rome, Ph.D. school seminar (A. Trentalance) -Orsay, Inv. speaker E. Coraboeuf Symposium (R. Fishmeister) -Oxford, Session Chairman XXIII meeting EWGCCE (Denis Noble) -Hyerres, Inv. speaker Colloque Canaux Ioniques (S. Richard) -Rome, Inv. speaker Hodgkin Symposium
2000	Jan Oct	-Milano Dept. Pharmacology (A. Panerai) -Parma, Inv. speaker SIBPA Congress
2001	Feb July Sept. Nov	-New York, Columbia Un. (R. Robinson) -Paris, Inv. speaker 3 rd Workshop Cardiac rate inhibitors. (Servier) -Ancona, Inv. speaker Congresso SIF -Goettingen (D.W. Richter, E.Neher)
2002	July Sept Sept Sept	-Courbevois Paris seminar (Servier) -Berlin, Inv. speaker Eur. Soc. Cardiol. Congress 2002 -Leeds, Inv. speaker Physiol. Soc. meeting - Montpellier, Inv. chair EWGCCE 2002 meeting
2003	March March May June Aug Sept Dec Dec	-Courbevois Paris seminar (Servier) -Les Arcs, Inv. speaker European Winter Conference on Brain Research -Milano, Organizer Symposium to honor A. Ferroni -Strasbourg, Inv. speaker Heart Failure Congress ISHR 2003 -Vienna, Inv. speaker Eur. Soc. Cardiol. Congress 2003 -Erice, Inv. speaker 2nd L. & H. Fairberg Workshop Cardiac Engineering -Milano, Ph.D. School in Physics seminar (PF Bortignon) -Milano, Accademia dei Lincei (F. Clementi)
2004	Jan Aug Sept Nov Dec	-Milano, Newron seminar -Sidney, Inv. speaker XVIII World Congress Intern. Soc. Heart Research -Montpellier, Inv. speaker Cardiac Cell. Electrophysiol: From funny currents to the current Physiome, Celebration for Denis Noble retirement -Napoli, Inv. speaker VI Convegno Nazionale INBB -Roma, Inv. speaker 65 ^o Congresso Naz. Soc. Italiana Cardiologia
2005	Feb Apr June Sept Dec	-Milano, Newron Pharmaceutical (R.G. Fariello) -Roma, Istituto Dermopatico Immacolata (M. Capogrossi) -New York, Dept. Pharmacol. Columbia Univ. (R.B. Robinson) (no seminar) -Milano, CC Monzino (M. Pesce) -Neully sur Seine, Procoralan Meeting (Servier)
2006	Apr Apr June	-S. Francisco, Inv. speaker Exp. Biology meeting FASEB (S.Siegelbaum) -Athens, Inv. speaker Cardiology Update 2006 Evagelismos General Hospital -Milano, H San Raffaele (A. Malgaroli)
2007	Feb June Sept	-Darmstadt (G. Thiel) -Bologna, Inv. speaker XIX World Congress Intern. Soc. Heart Research -Manchester, Inv. speaker Cardiac Electrophysiol. meeting (M. Boyett)

	Sept Oct	-Antalya, Inv. speaker 5 th Fairberg workshop (S. Sideman) -Lugano, Inv. speaker Cardiocentro Ticino Cong Cardiac Frequency (T.Moccetti)
2008	Jan Feb May June June June July Oct Oct Oct Oct Nov Nov Dec	-Vellere, India, Inv. speaker 6 th Winter Symp. Cardiov. Sciences -Geneve, Hôpitaux Universitaires de Genève -Servier (B. Wagner) -Athens, Inv. speaker XXVIII Europ. Section Meeting ISHR -Paris, formal ceremony in the Coupole, Institut de France, to receive the Grand Prix Scientifique award from the Fondation Lefoulon-Delalande -Milano, Keynote Lecture Giornate del Gruppo Biologico -Sassari seminar Dip. Scienze Biomediche (L. Deiana) -New London, NH Inv. speaker Gordon Res. Conference Colby-Sawyer Cardiac Regulatory Mechanisms (D. Eisner, J. Lederer) -Imola XV Cong. Soc. Ital. Ric. Cardiovasc. (G. Losano) -Milano Inv. speaker Circolo della Stampa, Premio Galeno 2008 (R. Paoletti) -Roma Inv. speaker Giornate Ricerca Servier (B. Millet) -Venice Inv. speaker Multiple Risk Factors in CVD Venezia Lido (R. Paoletti) -St Louis, MO CBAC Seminar (Y. Rudy) -New Orleans Inv. speaker CES Annual Meeting -Milano, Lectio Magistralis Faculty of Science Univ. Milan
2009	Feb Feb March April May May May June June June Aug	-Paris Croissy, seminar Servier (L. Alliot) -Il Ciocco, chair session GRC Cardiac Arrhythmia Mechanisms (N. Trayanova) -Milano, Lecture Istituto Lombardo Accademia Scienze e Lettere -Padova, Lectio Magistralis and Prize Symp. “Translation in Cardiomyopathies: from genes to therapy” (G. Thiene) -Boston Inv. speaker Heart Rhythm 2009 Cong. (D. Packer) -Brescia, H.C. Burger Award Lecture “The history of the discovery of funny channels” 23rd Cong. Europ. Soc. Noninvasive Preventive Cardiol. “Cardiovascular Medicine in the Era of Advanced Technology” (C. Rusconi) -Paris Suresnes, seminar/talks Servier (J.-P. Vilaine) -Berlin, Inv. speaker Europace 2009 Cong. (J. Brugada) -Lousanne, Inv. lecturer Colloques Formation Continue, CHUV (Andres Jaussi, Servier Barbara Fritsche) -Kyoto, Inv. speaker 36 ^o IUPS Cong. “Pacemaker mechanisms” (D. Eisner, D. Noble); organizer & speaker Luncheon Seminar (Servier) “Targeting funny channels for clinical applications” -Ovodda, Sardinia, Lecturer meeting “Studio comparativo della longevità di quattro comuni della Sardegna (Ovodda, Tiana, Erula e Perfugas) primi risultati demografici e genetici” (L. Deiana)
2010	Apr June	-Levico Terme, Inv. speaker Congress SICOA –Le aritmie nel III millennio -Nice, Inv. speaker Cardioslim 2010, 10th World Congr. Cardiac Arrhythmias
2011	Feb Oct Nov Nov Dec	-Milano Ist Besta (S. Franceschetti) -Venice, Inv. speaker 2011 Venice Arrhythmias Congress (Raviele, Natale) -Porto, Inv. speaker Reunião Anual Núcleo de Técnicos de Cardiologia da SPC (Medtronic) -Roma, Inv. speaker Advances in Cardiac Electrophysiology (Calò) -Roma, Inv. speaker Soc Ital Cardiol
2012	May May June Sept	-Milano, Lecture Istituto Lombardo Accademia Scienze e Lettere -Boston, Inv. speaker Heart Rhythm 33rd Annual Sci Sessions -Paris Suresnes, Servier seminar (J.-P. Vilaine) -Manchester, Inv. speaker Phys. Soc. Cardiac & Resp. Themed Meeting Cardiac Arrhythmias (H. Zhang)
2013	March May	-Pavia, Inv. Lecturer PhD School Collegio Borromeo (V. Ricci) -Montpellier, Inv. Lecturer Colloque du Patch-Club

	July	-Paris Suresnes, Servier seminar (J.-P. Vilaine, C. Thollon)
	July	-Birmingham, Inv. speaker XXXVII IUPS 2013 Congress (M. Boyett, H. Dobryznski)
	Sept	-Ancona, Lectio Magistralis 64th Annual Congress Italian Soc. Physiology (SIF)
	Dec	-Benevento, Univ. del Sannio (F. Goglia)
2014	Feb	-Milano, Ist. Besta (M. DeCurtis)
	May	-San Francisco, Inv. Speaker Heart Rhythm 2014 Congress
	Sept	-Maastricht, Inv. Lecturer 39th meeting EWGCCE
	Oct	-Tianjin, China, The second Hospital of Tianjin Medical University, seminar (Prof. Li Guangpin)
	Oct	-Tianjin, China, Tianjin Medical University, seminar (Prof. Tian)
	Oct	-Tianjin, China, Le Ren Tang drug company, Tianjin Zhongxin Pharmaceutical Group Co., Ltd., seminar
	Nov	-Milano, Inv. Lecturer School Medicine Univ. Milano-Polo San Paolo (L. Imeri)
2015	Feb	-Magnes Prize seminar Be'er Sheva, Israel (Bernard Attali, Israel)
	Feb	-2014 Magnes Prize Lecture award, Israel Society for Physiology and Pharmacology, Hadassah Ein Kerem, Jerusalem, Israel (Alexander Binshtok)
	March	-The 350th Anniversary of the Royal Society of London- Celebration of DiFrancesco & Noble (1985) paper
	March	-Milano, Dept of Pharmacology Seminar (A. Panerai)
	May	-Milano, Dept Biosciences Lectio Magistralis "How funny to peek into the history of science" in occasion of Royal Society celebration
	June	-Milano, Inv. speaker EHRA Europace Cardiostim 2015 congress
	July	-Tianjin, China, invited lecturer Bioeconomy 2015 Congress, Tianjin Univ. Traditional Chinese Medicine
	Oct	-Milano, seminar International Medical School Univ. Milano (G. Cerri)
	Nov	-Rome, Inv. lecturer PLACE 2015 Congress (R. Cappato, L. Calò)
2016	Jan	-Pavia, Collegio Ghislieri Conference
	Apr	-Parma, Dip. Bioscienze Università di Parma (Emilio Macchi)
2017	March	-Genova, Italian Institute of Technology seminar (F. Benfenati)
	June	-Malta, inv. speaker Mediterranean Neuroscience Society 6th Conference 2017
	June	-Vienna, Carmeliet-Coraboeuf-Weidmann Prize Lecturer 41st EWGCCE Congr.
	Sept	-Pécs, Hungary, IV Europ Sect Meeting International Academy of Cardiovascular Sciences (András Varró)
	Nov	-Rome, Inv. lecturer PLACE 2017 Congress (L. Calò)
	Dec	-Cesena (Alma Mater Studiorum Bologna), seminar School of Engineering and Architecture (S. Severi)
2018	May	-Copenhagen Ion Channel Symposium Danish Royal Academy (N. Schmitt)
	June	-Padova Inv. lect. Dott. Ricerca Med. Specialistica "G.B.Morgagni" (G. Thiene)
	Nov	-Freiburg Inv. lecturer Inst Exp Cardio Med Universitäts-Herzzentrum (P. Kohl)
2019	May	-Bari Inv. lecturer SIF 23 rd Sch. of Physiology to honor M. Svelto (G. Calamita)
	June	-Milano, Celebration Symposium "A funny journey on the waves of the heart"
	Aug	-Paris, Chair ESC 2019 Congress symposium "What makes your heart beat"
	Sept	-Bologna, Federation European Physiological Societies-SIF Congress Chair Symposium Cardio. Physiol. Genetic and epigenetic control of cardiac rhythm
	Nov	-Rome, PLACE Congress 2019 Chair Symposium on iPS cells
2020	Feb	-Milano, seminar IBF-CNR
2021	March	-Manchester (virtual) TARM Webinar, Division Cardio.Sci. Univ. Manchester "The road to pacing". https://zoom.us/rec/share/MBvdTV4LerMvYKwxFdXPK9Jx8OqAoEVO8S_fzVlhj3EuX2vidKmmYDFIkV5-7Cu.0leG_Oe3CE6yopLm

Synopsis of work

The heart of an adult person beats normally some 100,000 times a day, with a fairly regular rhythm. The heart rate is finely regulated at any time during our life according to need: for example, it slows at night and accelerates at wake-up, and changes rapidly during physical exercise or in response to varying metabolic and emotional conditions. A major physiological controller of heart rate is the autonomic nervous system, which causes acceleration by sympathetic stimulation and slowing by vagal stimulation through the release of the neurotransmitters noradrenaline and acetylcholine, respectively. How is the cardiac spontaneous activity generated, and how is rate controlled so rapidly and efficiently? These are central questions which have always attracted the interest of physiologists and cardiologists.

Just over a hundred years ago, Keith and Flack first observed that the heartbeat originates from a special region within the right atrium, the sinoatrial node (SAN). Only about seventy years later, however, did the cellular basis for the initiation of the heartbeat become apparent thanks to microelectrode recordings of electrical activity. Indeed, cells from the SAN region, termed “pacemaker” cells, generate action potentials with a special shape, characterized by the presence of a phase called “pacemaker” or “slow diastolic” depolarization. After termination of an action potential, rather than stabilizing to a certain “resting” level as in working atrial or ventricular myocytes, the membrane potential of a pacemaker cell slowly depolarizes until reaching threshold for another action potential, thus giving rise to spontaneous activity.

The discovery of the cellular mechanism underlying diastolic depolarization and driving pacemaker activity and control of heart rate has been the major achievement of the early research of Dario DiFrancesco.

In the late '70s, working in Denis Noble's laboratory in Orford with Hilary Brown and Susan Noble, the author described for the first time the cardiac so called “pacemaker” current, a large inward current which slowly activated on hyperpolarization within the range of diastolic voltages. The current had very atypical biophysical properties, since no other known current at the time had similar features, and was dubbed “funny” (I_f) for this reason. These features were, however, perfectly suited for generating the diastolic depolarization phase of the action potential of pacemaker cells, hence spontaneous activity. So, I_f could be a real “pacemaker” current! A second finding made during the same study was even more striking: I_f was increased by adrenaline, and could therefore be the current responsible for the acceleration of rate during sympathetic stimulation.

These were breakthrough findings which identified what appeared to be the long sought cellular mechanism able to induce spontaneous activity in pacemaker cells. According to this mechanism, pacemaking was generated by activation of the funny current at the end of an action potential, which initiated diastolic depolarization; also, the funny current controlled the rate of diastolic depolarization, hence the heart rate, and was responsible for frequency acceleration during adrenergic stimulation.

These first basic findings were published in 1979 in a Nature paper, and were followed by several studies in the following years. Many more data were collected by the author and by other laboratories on the properties of the funny current which further confirmed its role in the generation of cardiac pacemaking and in the control of rate. Some of the most relevant findings are outlined below.

In 1981, a major advance in the understanding of pacemaking was the reinterpretation of the pacemaker mechanism in another type of myocyte capable of spontaneous activity, the Purkinje fibres of conduction tissue. The pacemaker mechanism thought at the time to operate in these cells was the decay of a potassium current, the so called I_{K2} current, occurring during diastole. This theory was well established and universally accepted by the scientific community. In two companion papers in the Journal of Physiology, Dario DiFrancesco showed that I_{K2} ,

previously interpreted as a K^+ current, was instead a disguised funny current, and that the two pacemaker mechanisms in SAN cells and Purkinje myocytes were therefore not different but just the same, mediated in both cases by activation of the inward funny current during diastole. This result allowed for the first time an integrated view of pacemaking in the heart. A theoretical model incorporating these and other experimental data was developed in collaboration with Denis Noble. This model, the first ever to investigate numerically the ability of the funny current to underlie the diastolic depolarization and the generation of rhythmic activity, indeed allowed the reconstruction of spontaneous action potentials and represented the paradigm from which subsequent cellular models of the heart were developed.

In 2015, the Royal Society of London celebrated the 350th years of the **Philosophical Transactions**, the first and oldest scientific journal ever. The celebration included several activities (see:

<https://royalsociety.org/journals/publishing-activities/publishing350/history-philosophical-transactions/>)

among which the collection and review of the most influential papers published in its long life. Starting from some 600 of its best performing papers, a selection committee filtered through and eventually identified 16 papers in Phil Trans A (physical sciences) and 17 papers in Phil Trans B (life sciences) as the best papers in 350 years. Authors included Isaac Newton, Michael Faraday, James Joule, James Clerk Maxwell, Osborne Reynolds, Antoni van Leeuwenhoek, Hans Sloane, Edward Stone, Alan Turing, Peter Medawar, David Marr to name a few.

Denis Noble and Dario DiFrancesco were ecstatic to realize that one of the 17 papers selected in Phil Trans B was the model paper written in 1985: DiFrancesco, D. & Noble, D. (1985) A model of cardiac electrical activity incorporating ionic pumps and concentration changes. Phil. Trans. R. Soc. Lond. B 307, 353-398; see

<http://rstb.royalsocietypublishing.org/content/370/1666>)

<https://doi.org/10.1098/rstb.2014.0316>

<https://blogs.royalsociety.org/publishing/a-conversation-with-dario-difrancesco-and-denis-noble>

Denis Noble was the only living author attending a special Royal Society ceremony in March 2015, and released this comment:

"It felt deeply moving to be present at this magnificent celebration as, I believe, the only representative of such a pantheon of greats in science from Isaac Newton and Antonie van Leeuwenhoek in the seventeenth century to Alan Turing and Peter Medawar in the twentieth. It is both an honour and a deeply humbling experience. No living scientist naturally feels it right to be included. I said nothing but felt their presence 'standing on the shoulders of giants', to quote Newton himself."

The first single-channel recording of I_f was reported by the author in 1986 in a Nature paper. This was a particularly demanding achievement because of the very small single-channel conductance (about 1 pS), today still among the smallest single-channel recordings ever published. This difficulty is reflected by the fact that only 20 years later have similar recordings been made by another laboratory, which fully confirm the 1986 results.

Another important result obtained in the mid '80s concerns the vagal modulation of heart rate. Until the late '80s, the generally accepted interpretation of the action of the vagus nerve on rate was that parasympathetic-induced slowing is due to activation of an acetylcholine-dependent K^+ current in pacemaker cells. However, the existence of a pacemaker mechanism based on funny channels raised the question whether this latter mechanism could also participate in the vagal control of rate. In a series of papers in 1987-1989 from the author's lab, it was found that acetylcholine had a strong inhibitory action on the funny current, according to a mechanism opposite to that exerted by noradrenaline. These findings challenged the established view of a K^+ permeability increase as the cellular process underlying vagal control of rate. Indeed, the author and collaborators showed in a 1989 paper published in Science that the funny current inhibition,

and not the K^+ -conductance activation, was responsible for the slowing of pacemaker rhythm at low acetylcholine concentrations.

In the early '90s, in a publication in *Nature*, DiFrancesco demonstrated for the first time the action of the intracellular second-messenger cAMP on funny channels. This molecule acted by direct binding to the channel protein, and not by a phosphorylation process. Activation by cAMP represented the mechanism responsible for I_f increase by sympathetic stimulation, and for I_f inhibition by parasympathetic stimulation. An important consequence of these findings is that they led to an integrated view of the entire process by which the autonomic nervous system modulates heart rate by means of the funny current. In brief, sympathetic stimulation leads to increased intracellular levels of cAMP, a consequent increase of the funny current, and therefore to an increased slope of diastolic depolarization and rate acceleration; conversely, parasympathetic stimulation leads to exactly the opposite set of events and therefore to rate slowing.

These fundamental early discoveries, integrated by other data such as the cloning of the molecular correlates of native funny channels (the HCN channels, for Hyperpolarization-activated, Cyclic Nucleotide-gated), have eventually led to the development of major clinically-relevant applications.

1. Application to the genetics of cardiac rhythm disorders. Of the 4 HCN channel isoforms known, HCN4 is the most highly expressed in the sinoatrial node (SAN). In one of the first studies investigating the potential link between dysfunctional HCN4 channels and Sinus Node Disease, the author's lab showed that a form of asymptomatic sinus bradycardia, found in a large Italian family, is associated with a point mutation of HCN4. The mutation is loss-of-function, i.e. it reduces I_f during diastole, thus slowing spontaneous frequency and generating bradycardia. This result is important in that it represents a specific case of a broader mechanism for rhythm disturbances based on constitutive alterations of funny channels.

A few years later, also a gain-of-function mutation was found and reported by the PaceLab. In perfect agreement with the functional role of the funny current according to which increasing the I_f availability is bound to accelerate the heart, this mutation led to a tachyarrhythmia (Inappropriate Sinus Tachycardia, IST).

A large number of cases where rhythm disorders are caused by HCN4 mutations have been reported by several laboratories including that of the author, and more are likely to be found with further investigation.

2. Application to the field of "biological pacemakers". These are auto-rhythmic cellular substrates able to induce or control pacemaker activity, which may eventually replace the electronic pacemakers used today. These new biological devices are based upon the induction of pacemaker function in silent cardiac tissue by the transfer of funny (or HCN) channels. This can be achieved by means of viral transfection or by transfer of cells engineered to overexpress HCN channels, or expressing funny channels constitutively. The PaceLab has shown that the isolation from mouse Embryonic Stem cells of a non-teratogenic population of cardiac precursors is able to mature and form a fully functional pacemaker-like tissue.

While several proof-of-principle experiments have shown that biological pacemaking is indeed possible, the road to its clinical application is still a long one.

3. Application to pharmacological control of heart rate. This is the most important application of the concept of funny channel-based pacemaking, since it has led to the development of therapeutic tools now commercially available for the cure of specific cardiac diseases.

The beneficial effect of heart rate slowing in cardiac diseases such as angina, ischaemic heart disease and heart failure is well known; also known is the association between high resting heart rate and cardiovascular or all-cause mortality. Presently used therapies with β -antagonists and calcium blockers ameliorate mortality risk in part because of their heart rate-slowing effects. However, these drugs affect other cardiovascular and non-cardiovascular parameters and may also have adverse side-effects (for example a reduced inotropic function).

Since funny channels have a basic role in heart rate modulation, they clearly represent an important target for the development of drugs aimed to specifically control heart rate, without

complicating side effects. Several drugs acting on funny channels have indeed been developed by drug companies in the last few decades, with the aim of reducing heart rate specifically. Among them ivabradine, developed by Servier, is the only drug having passed all clinical tests. The PaceLab has clarified some molecular aspects of the mechanism of action of ivabradine on funny-channels and consequent heart rate-reducing effect. These results provide a detailed explanation for the "use-dependence" of ivabradine, a clinically very useful property according to which high rates are affected more vigorously than slow rates.

Ivabradine is available with the commercial name of Procoralan or Corlentor (also other brand names), and is prescribed against chronic *angina pectoris* and heart failure. Many clinical trials, some quite large, have investigated the clinical efficiency of ivabradine in reducing morbidity/mortality of coronary heart disease and systolic heart failure patients, among which BEAUTifUL, SHifT, SIGNifY, MODifY, EDifY, and others. In fact, 22 trials on ivabradine are listed in the Servier Trials web page (<https://clinicaltrials.servier.com/?s=ivabradine>).

In summary, the discovery of the funny current and its role in the generation of spontaneous activity and control of heart rate has been a fundamental achievement in the understanding of the basic physiology of the heart, and has also resulted in the development of important clinical applications.