Acceptance speech for Swanlund Chair

I'd like to begin by thanking the Swanlund family for their magnificent bequest to the university, and the Chancellor, Provost, Dean and Head of Physics for their roles in bestowing this fabulous award on me.

I propose to use my time to talk to you about Collective Effects. With such a diverse audience, it seemed to me, as a teacher, that I owe it to you to explain in my own words what I do, and why I think I have received today's honour. Fasten your seat belts …

This is a picture of a field of tulips. In Holland, during the early part of the 17th century, tulips became very popular, and everyone wanted to buy them. Each transaction involves two people, the buyer and seller, but what happens when each buyer is a seller to someone else, and each seller has been and will be a buyer to others? Then you get a complex network of transactions, kind of like the one shown in this picture. The picture is not the tulip-market network, but the Federal Reserve Interbank network, but I don't expect that there would be much difference.

The important thing is that when there is enough connectivity, the network becomes alive! It starts to forget what it is made of, and behaves according to new rules: as long as there is enough money floating around, everyone plays a game where they buy a tulip, and sell it at a higher price. It doesn't matter how much they paid for it, because in a large network, you can always find someone who will pay more for it than you did. And so the price of tulips just keeps getting higher and higher. According to one estimate, by 1637, the best tulips were worth about $76,000 in today's money.

The new rules of the network are the outcome of the activity of all the people in the network. This dynamic is called a Collective Effect, because it relies on there being lots of players, all of whom are behaving in a way determined by the other players. We can't predict what any one person is going to behave like, but the behavior of the group is predictable and follows reasonably well-understood rules.

Now eventually, we run into a problem: there is not enough real money around to keep this collective behavior going for ever. Then you can't be sure to find a buyer for your ridiculously-priced tulip, and so you are stuck with it. Once everyone realizes this, no one wants to buy anything, and so there are fewer transactions. The network falls apart, and now it looks like <u>this</u>, much sparser than before.

The Wall Street Journal calls this a liquidity crisis, and the one in 17th century Holland had long-lasting repercussions. However, such frantic "up-down" behavior is not uncommon in financial markets, as you can see here in this graph of IBM stock over 35 years. Tulips may be an unfamiliar form of money, but they are not the strangest I want to tell you about today. The strangest form of money currently traded is genes: and the traders are microorganisms and viruses! They also experience boom-bust phenomena, as do other systems in biology and physics, where collective effects are important, such as in fluid turbulence. In this next picture you can see how the how the wind gusts change in speed on a really windy or turbulent day --- the up-down behaviour is just like the boom-bust behavior of financial markets.

The most prized tulips in 17th century Holland were ones that looked like this, striped because of an infection by a virus called the *Tulip-breaking potyvirus*. This little virus influenced an entire economy and had an impact that lasted for hundreds of years. This weird amplification is an example of biological complexity, the connected but acausal dynamics of active complex systems. It is likely that many of the events that govern our daily lives are influenced by this sort of physics; not just the weather or financial markets, but also the failure of antibiotics, colony-collapse disorder in honeybees, and the stability of Earth's ecosystems.

Although today, I am mostly interested in biological complexity and fluid turbulence, I still pursue my first loves which are statistical physics and pattern formation. With Eshel Ben-Jacob and others, I studied how snowflakes grow, and our work led to a detailed understanding of materials microstructures. We discovered that you can make air bubbles grow into snowflake shapes!

The fact that such different things as air bubbles and atoms in a metal, or tulip markets and turbulence, can behave the same way is beautiful and profound. It shows that if you want to understand something, it is not always a good idea to do the obvious thing and see what it is made of. Instead it is better to understand what sorts of Collective Effects are present. This is not obvious, and the lesson has not yet been learned by biologists.

The branch of science that really developed and exploits this idea is called condensed matter physics, and I am proud to be a member of what is universally agreed to be the best condensed matter physics group in the world --- the one right here. One of the things we are famous for is superconductivity. In a superconductor the electrons inside the superconducting material form a quantum marketplace, trading neither money, tulips nor genes, but instead sound waves or perhaps magnetic spin waves. Superconductors do many strange and remarkable things, such as pushing on magnetic fields so hard that they can actually levitate – like this. By studying how this process happens at low temperatures, I deduced that high-temperature superconductors must be in a certain sort of quantum state, one that was first observed right here in Illinois by my friends Dale Van Harlingen and the late Donald Ginsberg and their students.

My own work studies these sorts of phenomena, by using tools such as <u>this</u> page of analysis. However, I sometimes use other tools such as supercomputers, although nowadays they don't tend to look quite like <u>this</u>.

These pictures show you how important to me are my family; my wonderful wife Joan, and my dear children Zippy and Zoë. Their love, support & unusual questions are vital to me: "Thank you – I would not be here today without you!" I also want to thank Joan because it was her insights and deep knowledge of Biology that first made me realize that it could be an interesting subject. I want to thank my family in England for my warm upbringing and education: my brother Anthony, mother Alice, who I'm thrilled came all the way from England to be with us, and my father Jack, who would have been very proud today. My father imparted to me a deeply questioning attitude that has served me well in all things. I also want to acknowledge my family in Chicago for their support and interest, and for being here today.

I've also benefited from many brilliant colleagues and wonderful students. I want to say "thank you" to them, to conclude these remarks. Paul Goldbart is a cousin, friend, and collaborator on Collective Effects in polymer networks. Together, we figured out why rubber is solid. I want to thank him especially for his leadership of the condensed matter theory group, most notably in establishing the Institute for Condensed Matter Theory. Yoshi Oono influenced my thinking even when I was a student in Cambridge, long before I came here. He sees further and deeper than anyone I know, and changed the way I think.

During the last few years, I have worked at Yellowstone National Park, trying to understand the microbiology and geophysics of this remarkable place. Perhaps our work will shed light on the origin of life, and give us ways to look for life on other planets. I thank Bruce Fouke for getting me into this, and for nearly 7 years of close and intense collaboration, with many fine students, especially John Veysey and Hector Garcia Martin, shown here.

I benefit greatly from membership of the College of Engineering, and I've worked especially closely with two friends who I want to acknowledge today. Jon Dantzig, collaborator on materials science, and fellow Chopin enthusiast, just "gets it", whatever "it" is, faster than pretty much anyone else I know. Gustavo Gioia is my close collaborator on turbulence -- a true scientific Romantic who sketches what he sees around him in a little notebook, and argues passionately about the technicalities of fluid dynamics in a way that is a captivating combination of Jane Austen and Franz Kafka. Thank you both for keeping my feet on the ground and my head in the clouds.

I could not have done my work without the support, friendship and infrastructure of our unique and famous physics department, and its succession of wise Department Heads. I have over the years collaborated with many of my colleagues, and each collaboration has been exciting and rewarding. More recently, I have begun to work with a small but intrepid group of biologists at the Institute for Genomic Biology. To all of you, physicists, biologists, geologists, engineers – thank you!

I want to thank my mentors, from whom I learned that physics is not just a set of problem-solving exercises, but a way of looking at the world that is most powerful when applied to things that don't at first seem to even be physics. Sam Edwards, my advisor; Jim Langer, my postdoc advisor; and Grisha Barenblatt, whose work especially inspired my own contributions to renormalization group theory. Over the last few years, I have been lucky enough to count as close friend and collaborator Carl Woese. Carl was trained as a physicist, but saw the light earlier than anyone else, and used a physicist's way of thinking to transform biology and evolution, in ways that are not even today fully-appreciated.

The last "thank you", however, goes to my students and postdocs over the years. Thank you for working with me; thank you for laughing at my jokes, and thank you for taking seriously the passions and furies that drive our science. This award recognizes Collective Effects, and it would not have been possible without you, and my other collaborators shown here. Thank you.