PROFESSOR RAVI R. MAZUMDAR

UNIVERSITY OF WATERLOO, CANADA

President Nikias, Dean Yortsos, Mrs. Sophia Balakrishnan, Professor Petros Ioannou, and friends,

As one of Professor Balakrishnan's former Ph.D. students it gives me great pleasure to partake in the investiture of Professor Ioannou as the A.V. Balakrishnan Professor here at USC. Professor Ioannou embodies the qualities that Bal always adhered to: scientific excellence and a strategic vision.

Professor Balakrishnan came to USC in 1946 to become a filmmaker but found the environment so stimulating and facilitating that he went on to become an applied mathematician par excellence and his work has impacted every facet of engineering where mathematics and models play a role.

The speakers before me have spoken about his human qualities and so I would like to give you an idea of Bal's immense contributions to mathematics, communication theory, control theory, signal processing, stochastic control and filtering, infinite dimensional systems and of course his last preoccupation, providing a mathematical framework for aeroelasticity and aerodynamics. There are few scientists who can claim such a vast scope of research but what is unique is that Bal's contributions have been seminal in that his work engendered new frameworks and methodologies. He was driven by problems and often invented the mathematics to solve them.

His initial work was on fractional powers of operators that grew out of his Ph.D. with Ralph Phillips. His professional career began with addressing problems motivated by space communications. His work on sphere packing bounds for signal constellations in communication systems has barely been improved and forms the basis of reliable wireless communication today. In a similar vein his extensions of the Shannon sampling theorem to random signals is today the bread-and-butter of all statistical processing and a result taught in graduate courses in random processes. In the 1960's Bal began a very fruitful collaboration with Lucien Neustadt of USC in optimization. It was during this phase that Bal developed the so-called epsilon-technique in optimal control – a precursor to the celebrated Pontryagin's Maximum Principle as it is now known in control theory. In control systems, through his introduction of semi-group theory he provided tools

for studying control of systems driven by partial differential equations. A particular important outcome of this theory was the explanation of the flutter phenomenon that was responsible for many accidents of planes in trans and supersonic speeds. This explanation could not have been possible or even predicted via the standard finite element methods.

In the late 1970's and 80's Bal was at the forefront of developing a function space approach to stochastic control. His creation of white noise theory has been instrumental in being able to work with real data, but his contributions have gone far beyond just the formulation, it facilitated a framework to handle infinite dimensional stochastic models like turbulence. Here we see one of Bal's great capacities – white noise theory was developed because Bal realized that the elegance and power of Ito calculus was simply hopeless when applied on real data.

The 90's saw Bal return to his initial love: infinite-dimensional systems and partial differential equations. In 2010, at the ripe age of 87 he completed a 600 page monograph on the continuum theory for aeroelasticity that has been acknowledged by both the aerospace community and the applied mathematics community as a masterpiece. He wrote in the introduction that "a second volume will follow." Hopefully someone capable will be able to bring his ideas to the world scientific community.

That Bal's mind was ever curious is reflected by a collaboration between us in 2010. One day he called to say that he had been wrong in asserting a certain property with white noise and asked me if I could think about it. It culminated in a paper published in the *IEEE Transactions on Information Theory* and what is gratifying is that the result is a special case of work by Martin Hairer that has been awarded the Fields Medal (the math Nobel) in 2015. Of course this was completely independent of Hairer's work but driven by justifying certain assumptions made in condensed matterphysics!

It was not easy to be Professor Balakrishnan's Ph.D. student. He wanted students to develop their own ideas, without being forced to proceed with research as the thesis advisor saw fit. This was his way of making his students confident. He taught us that to be a good researcher we must judge and not be afraid, not be taken in my tools but address the problem and develop tools only if you need them. The end result was exhilarating, but the process was nightmarish. He never directed the line of research, but always willing to discuss the issues and point out directions. His proximity was enough to enthuse his students.

In his career Bal published over 300 papers, mostly single authored, and wrote 13 books. In addition to his scientific contributions, Bal played a vital role in opening the mathematics of the Soviet era to the West. He was quick to realize the importance of Pontryagin's work and the Soviet school of probability started by Kolmogorov. He helped found many journals like *Applied Mathematics and Optimization*, *SIAM Journal on Control* and the *IEEE Transactions on Information Theory*.

It is thus very gratifying and apt that the name of Bal has come a full circle to the place that launched his scientific career through the magnificent gesture of Mrs. Balakrishnan who was so beloved to him. His legacy is a difficult one to follow, but with Petros Ioannou as his inaugural chair holder it is in good hands.

Thank you.