…mixing and matching mindsets, identifying the limits of chemical sensing, and following photons from generation to detection…

(Prem Kumar, DSO program manager)

I want to push scientific and technological boundaries in domains where the basic sciences of physics, chemistry, and biology intersect with engineering and the recent strides in signal processing and computation. I firmly believe that big discoveries and revolutionary advances are waiting to be uncovered if communities from such disparate disciplines come together to tackle the big challenges that face us today. This belief did not just form overnight; it has its roots in my education and training as a physicist, but then growing up professionally researching and teaching in an engineering department. My specialty is optics and photonics, from the very basic on one hand in the areas of quantum optics and quantum computing to the very applied on the other in areas such as lasers, optical communications, imaging and sensing. I'm on leave from Northwestern University where I am a professor in the electrical engineering and computer science and physics and astronomy departments.

I am interested in the fundamental limits. How best can something be done and why can't we do better? Let me illustrate by an example. I'd like to remotely sense the presence of a toxic compound in air or on the surface of an approaching vehicle, and without raising any false alarms. What are the limits in being able to do so that are dictated by the basic laws of physics and chemistry and the assumptions made in applying those laws in engineering a system? Can a single molecule of a toxin be detected remotely in the presence of a gazillion benign molecules in the ambient environment? If not, why not? And what dictates the limit, the underlying science or the technology?

In the context of light detection, when is the exact moment a quantum of energy disappears as an electromagnetic wave (that is, a photon of light) and appears as a material excitation (an electron-hole pair in a semiconductor, for example)? Can that be time-stamped at the precision of the most accurate clocks of today? Can I create a photon of a pre-specified character where and when I want one? Can understanding such processes lead to better devices for quantum manipulation and sensing, such as seeing through fog at optical resolution? Are there efficient algorithms that would allow us to image through complex, highly scattering media, such as sandstorms?

If you are interested in helping me answer any of the above or related questions, I'd be happy to hear from you.

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