Dr John Noto gives an account of his work in the field of remote sensing and interferometry, and outlines his background and the first two decades of the company he founded to provide solutions in this area.

Looking up

Could you first provide an insight into how you came to collaborate with Dr Robert Kerr and what sparked the formation of Scientific Solutions Inc. (SSI)?

Bob was my PhD thesis advisor; I was close to finishing my doctorate and we were in the midst of a recession, so I started a small company out of my apartment to develop tuneable liquid crystal Fabry-Pérot technology. We won a National Science Foundation (NSF) Small Business Innovation Grant, and it was off to the races – I still can’t believe May 2015 will mark the 20-year anniversary of this venture!

Are there any other fundamental collaborations you would like to highlight?

Our most important collaboration is with the observatories that host our equipment. This dramatically increases the success and science output of our work.

On a personal level, what excites you most about the field of astronomy?

I’ve always been fascinated by remote sensing, which can determine what’s far away simply through observation. I’m amazed I’ve been able to make a living by ‘looking up’!

With more than 25 years in optical R&D, how has your background equipped you for your current role as President of SSI?

Since I’ve hired really good people, managing is easy. The hard part is sales; it’s a good thing my father was a salesman! I suppose my background has helped most in terms of reinvention. SSI started in optical telecoms, but then the market collapsed so we retooled into remote sensing. As technology has progressed, we have moved from ground to space-based remote sensing. We just delivered our first CubeSat to NASA for launch in September 2015.

Can you give a synopsis of SSI’s current projects and describe your progress to date?

Our current work is largely focused on remote sensing of the ionosphere and upper atmosphere; specifically the very top, which is called the thermosphere. Our satellite ExoCube will, for the first time, measure the density of hydrogen around the Earth. Hydrogen is an important source of protons and can have an effect on high-frequency communications. ExoCube will also measure helium, which is becoming important in calculations of satellite orbits. Our ground-based measurements complemented with our space-based work will provide a complete picture of the top of the atmosphere.

What are the end goals of this work?

Ultimately, we want to be able to predict how the atmosphere, both the ionised and neutral parts, will respond to solar events such as coronal mass ejection and solar flares.

What plans are in the pipeline for the company and your own work?

More space-based sensing, including novel sensors capable of probing the biosphere and plant growth from orbit, as well as sensors able to measure specific regions of the atmosphere.
EXTENDING AN AVERAGE of 17 km from the Earth’s surface is the troposphere, the lowest and smallest layer of the atmosphere that, nonetheless, accounts for around 80-90 per cent of its total mass. The upper boundary of the troposphere is marked by a temperature inversion: the higher the altitude, the colder the troposphere gets, until at the boundary of the stratosphere the temperature begins to rise once again.

The stratosphere extends another 50 km or so, and it is within this range that most aircraft fly and the majority of atmospheric ozone exists. Here, the temperature gradient inverts again, marking the beginning of the turbulent mesosphere where atmospheric waves, tides and winds exert their greatest influence. It is in the upper ranges of the mesosphere that the ionosphere, a region of atmosphere ionised by solar radiation, begins.

RESTLESS GAZE

Beyond the mesosphere, definitions of atmospheric depth become more irregular. Beginning around 85 km above the Earth’s surface, and extending between 400 and 900 km in height is the thermosphere, where the aurora occurs. Gas molecules in this region are extremely dilute and spread far apart, causing the thermosphere to reach temperatures of more than 2,500 °C. Above 160 km, molecules are so sparse that sound cannot travel, and even the extreme heat cannot be transferred at any noticeable rate. The separation between the mesosphere and the thermosphere also marks the turbopause; above this altitude, there are not enough turbulent forces to mix the chemical constituents of the atmosphere.

Between the Earth and the exosphere – the final layer in which the atmosphere begins to dissipate into space – there is a huge amount of variation in temperature, chemical composition, ionisation, turbulence and many other factors. All of these issues present obstacles for scientists wishing to make observations of space, or even the outer layers of the atmosphere itself. One group of researchers at Scientific Solutions Inc. (SSI) based in Massachusetts, USA, is working to address this issue. Co-Founder and President, Dr John Noto leads the company’s diverse team of observational space, atmospheric and planetary physicists – with collective experience exceeding 50 years – towards the challenging objective of devising novel remote sensing solutions for space situational awareness and measuring the near-Earth space environment.

THE MERITS OF INTERFERENCE

SSI has seen great success in recent years, generating a number of award-winning products with applications in imaging, defence, telecommunication and, most importantly, research. In particular, their R&D work has focused on the fabrication of air-gap Fabry-Pérot interferometers and tuneable liquid crystal Fabry-Pérot optical filters. Both of these devices are based on the same principles of interference, using two highly reflecting surfaces situated parallel to each other at some small distance or gap which defines the wavelength range of interest.

The gap can consist of air or of some other material, such as liquid crystal. A monochromatic light source can be broadened spatially and diffused to illuminate the non-reflecting side of one of the parallel plates. Light rays from different spatial positions will enter the gap. A small fraction will pass through the second plate, while most will be reflected back to the first plate. Some of these will pass through the first plate, but most will be reflected back to the second plate. Again, some will pass through, but most will be reflected, and so on. The rays that pass through the second plate have all travelled a certain distance or path length, although the distance or path length is not the same for each ray. This difference in path length is equivalent to a phase difference, and it is the phase difference which defines whether there is constructive or destructive interference of the rays. All the rays incident to the gap at a given angle and wavelength will constructively interfere; this effect can be engineered to create a very narrowband optical filter or high efficiency spectrograph.

Devices incorporating this technique have great functionality in both controlling and measuring the wavelength of light beams – two activities with importance in remote sensing and space observation.
INTERNATIONAL INTELLIGENCE

SPACE WEATHER – OBSERVING THE TOP OF THE ATMOSPHERE

OBJECTIVE
To measure the composition and dynamics of the near-Earth space environment.

KEY COLLABORATORS
Dr Jeff Baumgardner, Boston University, USA • Dr Rick Doe, SRI International, USA • Dr Josh Semeter, Boston University, USA • Dr Robert Kerr, SSI & Arecibo Observatory, USA • Dr Lara Waldrop, University of Illinois at Urbana-Champaign, USA • Dr Anthea Coste, MIT Haystack Observatory, USA • Dr Gary Bust, Johns Hopkins Applied Physics Laboratory, USA • Dr Geoff Crowley, ASTRA LLC, USA

PARTNERS IN OBSERVATION
Beyond SSI’s own facilities, some of its most important research accomplishments have been achieved through its partnerships with the observatories it helps to upgrade and maintain. The National Science Foundation (NSF) provided funding for the company to perform extensive upgrades of the optical systems at the Arecibo and Millstone Hill observatories, which at that time were between 30 and 40 years old. The move to modern, high-sensitivity, imaging interferometer-based systems meant higher precision, smaller error bars, more data and higher time-resolution for the measurements collected at these facilities.

PARTNERS IN OBSERVATION

SSI has been a lot of success in recent years, generating a number of award-winning products with applications in imaging, defence, telecommunications and, most importantly, research.

It was through their work with Arecibo that Noto and his colleagues were able to produce a paper on airglow and the role of the new, more advanced systems in facilitating its observation – research that Noto himself subsequently presented at the 50th anniversary of the Observatory. The publication presented information gathered by the Observatory’s newly upgraded interferometry system, and expanded on the fully automated system of operation and analysis algorithms that allow geophysical parameters to be calculated with an associated data quality index. The upgrade enables the system to make this information available each morning following the observations of the night before, in a methodology the SSI researchers refer to as ‘Data as a Service’.

In addition to their work with Fabry-Perot interferometers, SSI has fabricated a suite of systems used in the study of airglow. These instruments include a compact all-sky imager which images an entire 180° field of view with a narrow spectral bandpass onto a change-coupled device, a small photometer with no moving parts, a meridional spectrograph with a resolution of 2 nm or less, and a space weather station which is a turnkey housing unit with an optical dome and temperature-controlled interior used for space weather instruments. Several of these instruments are currently in use at the Arecibo and Millstone Hill observatories, while others are deployed in the field by SSI and collaborators.

NEW GROUND
Ground-based methods are suitable for observing airglow in the atmosphere, but to obtain a better view, it is necessary to move beyond the turbulent gases that sheath Earth. It is partly because of this that SSI has also been involved in a number of collaborations towards space-based observational systems. These have included two prominent satellite missions, one in collaboration with NASA’s Goddard Space Flight Center, the other with the US Air Force Space and Missile Systems Center (SMC). For these and similar applications, SSI has designed and developed a variety of optical devices for use in smaller satellites, including a light but robust spatial heterodyne spectrometer (SHS) and, in partnership with SRI International, a miniature ultraviolet photometer. The SHS technology acquires high-resolution images in two spatial dimensions. A distribution of multiple SHS on a fleet of CubeSats – miniature satellites, usually in the form of 10 cm cubes – can provide global coverage with a novel architecture for multi-wavelength discrimination and 3-D reconstruction. The miniature UV photometer uses novel optical, thermal and power control systems specifically designed for a small CubeSat, while maintaining the ability to be used in the study of various optical bands.

The ExoCube mission, a joint project between NASA Goddard, SSI and a number of partner universities, aims to develop a compact space weather CubeSat. CubeSats are very popular because they are versatile and simpler to construct. The Space Environmental Nanosatellite Experiment (SENSE), which is being spearheaded by the SMC, also aims to develop a CubeSat to provide operational space weather data. Both projects will demonstrate the feasibility and utility of the CubeSat model to organisations accustomed to much larger vehicles, and therefore light the way to new opportunities and functionalities that may come at a lower cost.

A SENSE OF THINGS TO COME
Over the almost two-decade period since its inception, SSI has continued to prove its value to its customers and partners, attracting funding from high-profile supporters like the NSF and carrying out projects in cooperation with NASA and the Air Force Research Laboratory. Over its lifespan, it has shown great flexibility in adapting to the demands of the market, and as it forays into space-based sensing continue to grow into the future, SSI appears set to continue its innovative history by facilitating new technologies for remote sensing.