Workshop Report

This is a report on a workshop held at Cornell University on March 30 – April 1, 2015. The workshop was held to honor Prof. Donald Farley on the occasion of his 80th birthday (belatedly) and also to consider the future of radio and space physics. About 60 scientists representing institutions in North America, South America, and Europe attended. Participants included some of the most senior scientists in the field, mid-career scientists, early-career scientists, and students. Along with radio scientists, the workshop was attended by NASA investigators, theorists, modelers, and a representative from NSF.

The focus of the workshop was the state of the AGS facilities. The first day of the workshop was retrospective in nature, and the second day considered contemporary research being performed with the facilities. The third day focused on discussions about the future. The discussions were vigorous and broad and extended to the vitality of not just the facilities but to geospace and heliospheric science generally.

A recurring theme of the workshop was the fact that incoherent scatter remains, by far, the most accurate and precise technique for studying the upper atmosphere, the standard by which other experimental techniques, ground-based and in situ, are validated and calibrated. Incoherent scatter experiments yield unambiguous estimates of the most important state parameters in the upper atmosphere with fine spatio-temporal resolution and offer the possibility of measurements with long-term continuity. Only sounding rockets make measurements with superior resolution, but sounding rockets are most often launched nearby incoherent scatter radars since the latter provide critical experimental context.

The incisive nature of incoherent scatter radar measurements will be crucial for resolving fundamental problems in geospace physics. For example, the *E* region/ lower thermosphere is a complicated region of geospace that remains poorly understood. This is the region where turbulence transitions to laminar flow, where molecular oxygen is dissociated, where ionization becomes abundant, where ions are unmagnetized whereas electrons are magnetized, and where strong neutral shears exist and electric currents flow. The dynamo fields which drive the ionosphere are generated here and modulated by neutral waves in a complicated way which couples the upper atmosphere to the lower atmosphere. Neutral atmospheric waves break here, but which waves penetrate and where the energy goes is unclear. Sporadic ionization layers which have grave influence on radio propagation exist here, but their generation mechanism and the influence of the underlying neutral dynamics is not understood. Ground-based remote sensing using our best experimental tool will be vital in elucidating the processes at work here.

Much of the discussion concerned the dichotomy between basic and applied research at the facilities, the two axes that define Pasteur's quadrant. Examples of basic research presented at the workshop included observations of heretofore unseen waves and turbulence in the lower thermosphere made using broadband measurements of the full incoherent scatter spectrum at Arecibo and HF interferometry at Jicamarca, observations of extraordinarily high-altitude irregularities over Jicamarca, and methods for inferring high-definition convection and current patterns with the PFISR. Applied research with the facilities includes long-duration, 24-7 observations of basic state parameters used to drive global space-weather models.

The relative merits of basic and applied research were discussed intently, both being advocated by different members of the audience. Some facilities are more suitable for basic research, others for applied. Increasingly, there is external pressure to emphasize applied research, which may be seen as having more direct societal impact. At the same time, significant discovery in aeronomy and space physics is clearly driven by basic research. Moreover, today's basic research leads to experiments and modes that support tomorrow's applied research, and operation in support of applied research can enable basic research, so the relationship is complicated.

**Ultimately, workshop participants agreed that both basic and applied research with the facilities are essential. They should not be rank ordered. They should both be supported.**

A second recurring theme at the workshop was the balance between experimental and modeling work in the geospace community. CEDAR began as a workshop for coordinating and evaluating the outcomes of experimental campaigns. Burgeoning interest in optical aeronomy gradually shifted the focus from the charged to the neutral species in the upper atmosphere. However, measuring the neutral species remains difficult, and perhaps as a consequence, the field has shifted from a primarily experimental one to one focused on numerical modeling. One could well come away from a CEDAR meeting with the mistaken notion that the sole purpose of experimentation is driving models.

The sense of the workshop was that this evolution has taken place prematurely. The models in widespread use in geospace science remain incapable of reproducing gross features in the facility observations, even during geomagnetically quiet periods. This is not because they are numerically flawed but because geospace science is still theoretically immature compared with physical oceanography and meteorology, for example, where numerical modeling is more successful. Assimilating models with globally-available but less incisive datasets like GPS TEC measurements papers over the problem rather than addressing it.

**Workshop participants believe it will be important to re-balance experiment, theory, and modeling appropriately if we are to move toward the goals we have set for ourselves in our planning documents.**

Finally, there was a realization during the workshop that geospace science has become an insular discipline and that this is inhibiting progress in a number of important areas. There have been tremendous technological breakthroughs in the field of radio astronomy, for example, that have not filtered into our closely-related field. Geospace science has identified waves and turbulence as a priority research focus but does not, generally, familiarize itself with related developments in ocean, atmospheric, or planetary science where important work is being done. Ionospheric plasma physicists are too often unaware of relevant progress in laboratory, solar, and cosmological plasma physics. The tendency is to cite, invite (to our conferences), and collaborate with only ourselves. Only now are CEDAR and GEM researchers beginning to communicate regularly.

**The workshop concluded that geospace science and engineering must begin to proceed collaboratively for progress to be made in the future.** Education would and should go both ways.

Aeronomy and space physics is a discipline at the crossroads. Our European colleagues are responding to the same challenges outlined above by building EISCAT-3D, facilitating a mix of basic and applied research, concentrating on better experimentation, and borrowing from lessons learned in radio astronomy and other fields.