The Warm Ionized Medium

Ron Reynolds

Introduction by Frank Scherb

I'm an old friend of Elihu, going all the way back to when we were undergraduates at MIT. My main reason for writing to you is to provide some background and history on a significant astrophysical research program that was started by Fred Roesler, Ron Reynolds, and me at the University of Wisconsin in 1968, with Elihu's guidance. We were trying to use optical astronomical observations to detect the presence of low-energy cosmic rays in our galaxy. Elihu realized that faint Balmer alpha emission from neutral interstellar hydrogen could be used as an indirect tracer of cosmic rays exciting the gas. On consulting with Pierre Connes in France as to the kind of instrumentation needed for such observations, Dr. Connes told Elihu that the Fabry-Perot spectrometers used by physicists at the UW were needed for this purpose. Elihu called me on the phone and asked if we would like to try this program. Ron Reynolds was my new graduste student at tne time, and he enthusiastically embarked on the program as his Ph.D. thesis research. Fred Roesler provided the Fabry-Perot instrumentation, and Elihu arranged access to the GSFC 36-inch telescope. He also brought Ron Reynolds and me to GSFC as visiting research associates from 1970 to 1973. We were successful in detecting the faint Balmer emission line, but subsequent observations showed that it was not due to cosmic ray excitation of interstellar hydrogen. On the other hand, the program has blossomed into a significant astrophysical study of the warm ionized medium in spiral galaxies, as described in detail in a recent paper in the Reviews of Modern Physics.

While Elihu was, of course, closely associated with high energy x-ray astrophysics, he also played an early and crucial role in opening up an area of astronomy at visible wavelengths, namely, the detection and study of faint optical emission lines from the wide spread, warm (10,000 K) ionized gas that permeates the disks and halos of spiral galaxies.

When pulsars were discovered in the late 1960s, their dispersion measures indicated surprisingly high amounts of ionization in the interstellar medium. Pulsars in directions away from the Galactic plane and away from the classical H II regions surrounding O and B stars revealed 100 times more free electrons along the lines of sight than could be accounted for by the ionization of trace elements such as carbon by ultraviolet starlight. The large number of free electrons could only be explained if 10% to 30% of the hydrogen within the diffuse interstellar medium was ionized. This was a perplexing development, because at that time everyone "knew" that hydrogen ionizing radiation from hot stars, the primary source of ionization in the Galaxy, could not penetrate the presumably ubiquitous neutral hydrogen filling the Galactic disk. Speculation about alternative sources ranged from low energy cosmic rays to bursts of ultraviolet light from supernovae.

Elihu recognized that, whatever its origin, perhaps this "out of place" ionized hydrogen could be directly observed and studied through the detection of its Balmer recombination line emission. The diffuse interstellar medium must be glowing in optical emission lines, and what was needed was an instrument with enough sensitivity to detect this very faint emission. Elihu sought out the renown spectroscopist Pierre Connes at the Observatory de Meudon, who directed him to the physics department at the University of Wisconsin-Madison, where Fred Roesler and Frank Scherb had the unique expertise and resources to design, build, and operate the high resolution, high throughput Fabry-Perot spectrometer that would be required. As Frank Scherb's graduate student looking for a thesis project, I was in the right place at the right time to begin what turned out to be a long adventure of detecting, exploring, and mapping a "new" component of the interstellar medium.

Very little funding was available initially. It was the generous support and encouragement provided by Elihu and the hospitality of Elihu's mother, the Orbiting Astronomical Observatory, and Goddard staff that helped get the project moving. The spectrometer was designed and built at Wisconsin and then assembled at the coude focus of Goddard's 0.9 m telescope in the autumn of 1969. The initial observations, though of modest signal-to-noise, were sufficient to establish that indeed the interstellar medium was aglow with faint hydrogen recombination line emission. Soon after, with Elihu's endorsement, I was awarded an NAS/NRC Postdoctoral Associateship and returned to Goddard to carry out more extensive observations over a two-year period with an improved spectrometer. Those observations confirmed that warm, nearly fully ionized gas was indeed widespread within the Galaxy, producing faint H-alpha and [N II] emission that covered much of the sky.

Continued spectrometer development, funded by the National Science Foundation, culminated in the late 1990s in the Wisconsin H-Alpha Mapper (WHAM), a stand-alone remotely controlled observatory, which operated for a decade at Kitt Peak, and which has now been relocated to Cerro Tololo to explore the southern sky. WHAM is providing the first all-sky survey of the distribution and kinematics of the diffuse interstellar ionized hydrogen in our Galaxy using the visible H-alpha line in a manner analogous to the earlier surveys of the neutral hydrogen using the radio 21 cm line.

Optical emission line studies by many investigators using a variety of techniques have now firmly established that diffuse ionized hydrogen is a major component of the interstellar medium within the disk and halo of the Milky Way and other galaxies. The large mass, thickness, and power associated with this gas have modified our understanding of the composition and structure of the interstellar medium and the distribution of ionizing radiation within galaxies. Its weight is a major source of interstellar pressure at the midplane, and a kiloparsec above the plane, it may be the dominate state of the medium. The study of the warm ionized medium has expanded to include many other emission lines, particularly the forbidden lines of trace atoms and ions that probe the physical conditions within the gas and their variation with location in the galaxy. O stars are now firmly established as the primary source of the ionization -- no other source of power is sufficient. However, it is still not clear how such a large fraction (20% - 60%) of the ionizing radiation from these stars, located in star forming regions near the midplane and surrounded by clouds of neutral hydrogen, is able to penetrate throughout the disk and into the halo.

Elihu's early idea to search for faint optical emission lines from diffuse interstellar gas initiated an new area of galactic astronomy that is now beginning its fifth decade. It defined my entire career, drew in others from around the world, spurred the development of large aperture multi-etalon Fabry-Perot spectrometers, and impacted areas of astrophysics ranging from large scale feedback processes associated with massive star formation to Galactic foreground contaminations of cosmic background radiations. Observers and theorists continue their struggle to understand the nature of this faint optically emitting gas, its ionization and heating, and the clues that it contains about galactic processes.