

The WHAM Survey of Ionized Gas in the Galaxy



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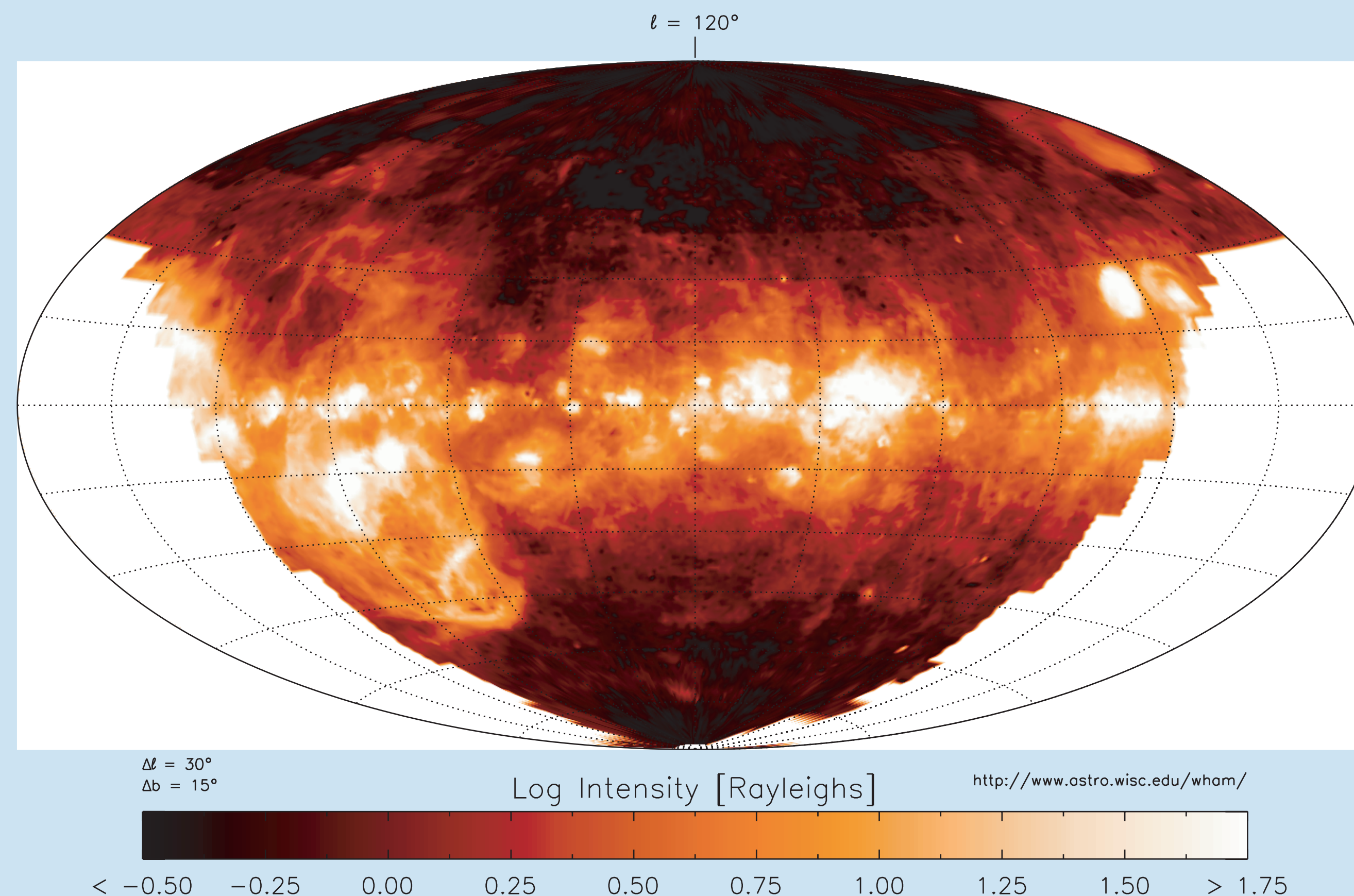
ABSTRACT

The Wisconsin H-Alpha Mapper (WHAM) is a high-resolution Fabry-Perot spectrograph optimized for studying optical emission from faint, diffuse sources. It features full remote operability and an unprecedented combination of high sensitivity (0.01 Rayleigh; emission measure of 0.03 cm⁻⁶ pc) and high spectral resolution (R=25,000). As its primary mission, WHAM has produced the first kinematically resolved survey of diffuse ionized gas in the northern sky comparable to all-sky surveys of neutral gas. The H α survey work has been extended to other diagnostic emission lines that are used to characterize the physical conditions of this poorly understood phase of the interstellar medium. The unique capabilities of WHAM have been used to study a range of other phenomena including the Earth's geocorona, the motion of zodiacal dust, large planetary nebulae, high-velocity clouds, and dwarf spheroidal galaxies. The instrument is currently in the process of being relocated from Kitt Peak to the southern hemisphere where it will complete the all-sky H α survey and continue to explore ionized gas in the southern skies.

THE H α SURVEY

The WHAM Northern Sky Survey consists of over 37,000 spectra centered on the Balmer- α line of hydrogen (Haffner et al 2003). WHAM measures the average spectrum within a 1 $^\circ$ circular field of view, with a resolution of 12 km/s over a 200 km/s spectral window. The maps shown here were created by integrating the spectra over the indicated velocity range. Interstellar H α is detected in every direction. The careful removal of emission from the Earth's geocorona, atmosphere, and reflected solar lines from zodiacal dust yields a sensitivity of 0.1 Rayleighs, corresponding to an emission measure of ~ 0.3 cm⁻⁶ pc. The Survey forms an important database for studying ionized gas in the Galaxy as well as understanding foreground emission to the CMB. The data are available at <http://www.astro.wisc.edu/wham/>.

Wisconsin H-Alpha Mapper Northern Sky Survey
Total Integrated Intensity Map ($-80 < v_{\text{LSR}} < +80$ km s⁻¹)



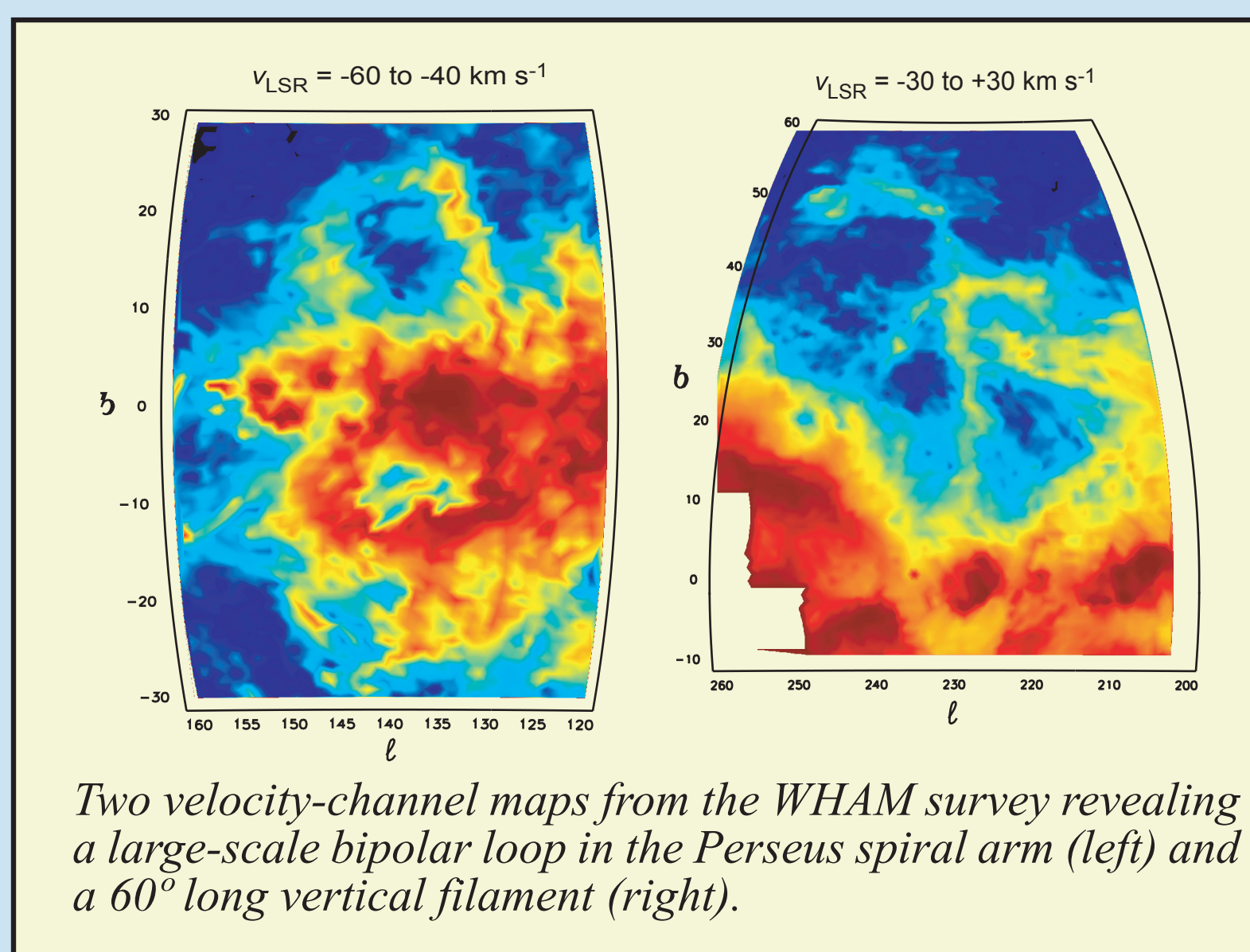
THE WARM IONIZED MEDIUM

The Survey has revealed several bright knots of emission near the Galactic plane (classical HII regions) as well as remarkable large-scale H α -emitting structures, including loops, filaments, and bubbles superposed on a more diffuse H α background. These structures are part of the Warm Ionized Medium (WIM), an important phase of the interstellar medium (ISM) that pervades the Galaxy (Reynolds 1991). With a scale height of ~ 1 kpc (Haffner, Reynolds, & Tuft 1999) and an enormous power requirement, the WIM plays a crucial role in our understanding of the physical conditions and dynamics of the ISM in general. Despite its importance, the origin and nature of the WIM is poorly understood. In particular, it is not clear how ionizing radiation from widely separated O and early B stars is able to penetrate the ubiquitous HI to ionize material over 1 kpc from the disk. Fundamental questions such as how the WIM is ionized, what is its source of heating, and how its structures are formed have only begun to be explored.

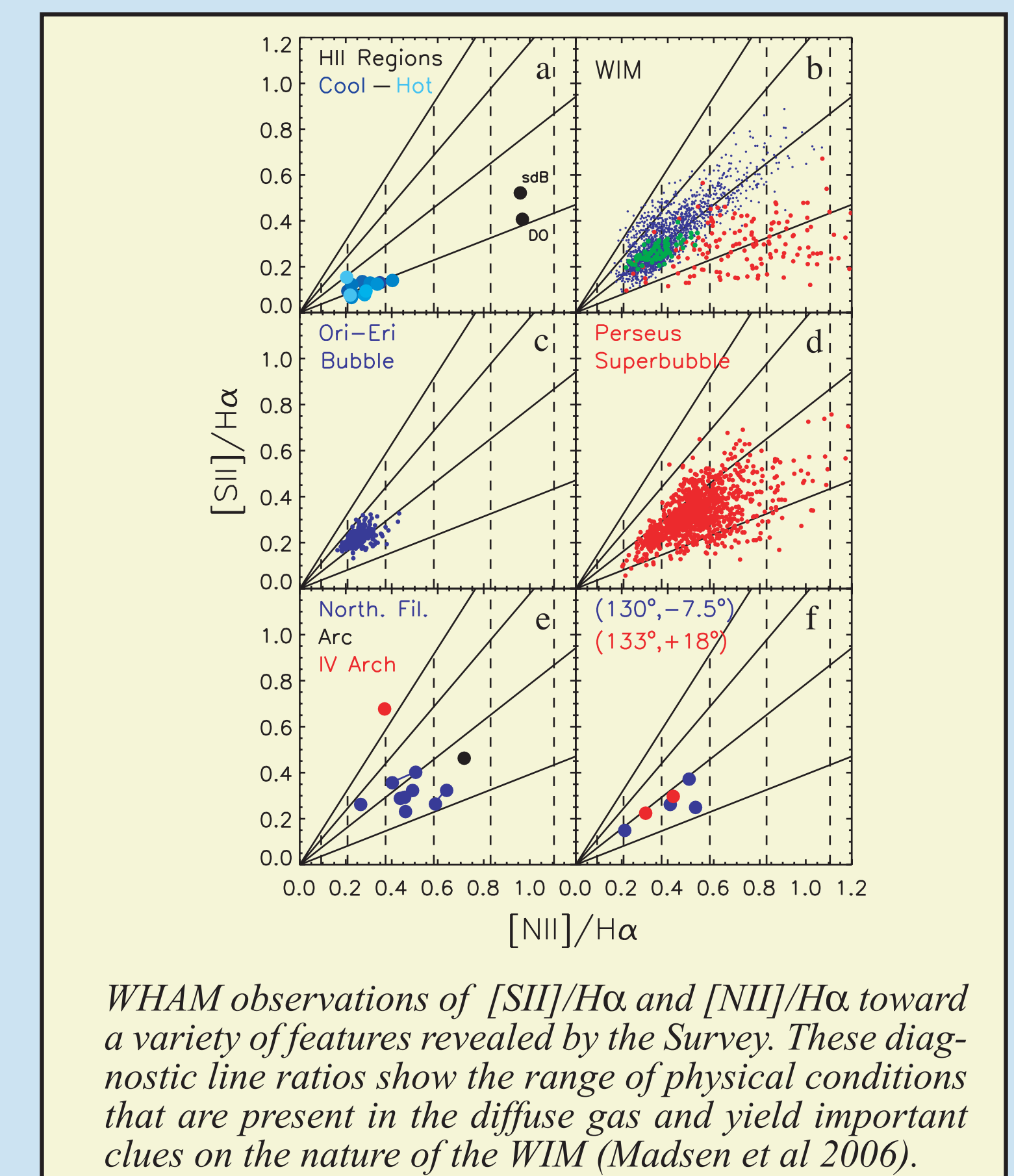
The physical conditions of the WIM can be inferred by observing a range of diagnostic emission lines. WHAM has surveyed large portions of the WIM in the lines of [NII] λ 6583, [SII] λ 6716, [OIII] λ 5007, and HeI λ 5876 (Madsen et al 2006). The panels on the right show the large variation in [SII]/H α and [NII]/H α which are used to infer the temperature and ionization state of the gas. In general, we find that the WIM is hotter and in a lower ionization state compared to classical HII regions. If the gas is ionized by photons escaping from HII regions, our results suggest that the ionizing spectrum is significantly modified as it traverses interstellar space. Recent three-dimensional photoionization models (e.g. Wood et al 2005) offer powerful new tools in understanding the physics of diffuse ionized gas and its role in how the Galaxy works.

THE VERSATILITY OF WHAM

While WHAM was primarily designed to study emission from diffuse ionized gas in the Galaxy, its unique capabilities have been used to pursue a range of other phenomena. The H α emission from the Earth's geocorona is a contaminant in the interstellar spectra, but it has been used in aeronomy to study the seasonal variations connected with the solar cycle (Nossal et al 2004). WHAM has measured the motion of zodiacal dust by tracing the Doppler shifts in the scattered solar Mg I line, placing important constraints on models of the zodiacal dust cloud (Reynolds et al 2005). We are conducting an emission line survey of large, evolved planetary nebulae; their large spatial extent and low surface brightness make it difficult to observe them with traditional spectroscopy techniques (Madsen et al 2006). WHAM has detected H α toward several high-velocity HI clouds, placing important constraints on the origin and nature of these enigmatic objects (Tuft et al 2004). We have looked for ionized gas off the edge of HI disk of M31, constraining the intergalactic radiation field (Madsen et al 2001). WHAM has searched for the ionized ISM of dwarf spheroidal galaxies, placing upper limits on their total mass (Gallagher et al 2003). WHAM will soon take advantage of its new home in the southern hemisphere, where it will complete the H α survey and continue its wide-ranging study of faint, diffuse emission.



Two velocity-channel maps from the WHAM survey revealing a large-scale bipolar loop in the Perseus spiral arm (left) and a 60 $^\circ$ long vertical filament (right).



WHAM observations of [SII]/H α and [NII]/H α toward a variety of features revealed by the Survey. These diagnostic line ratios show the range of physical conditions that are present in the diffuse gas and yield important clues on the nature of the WIM (Madsen et al 2006).