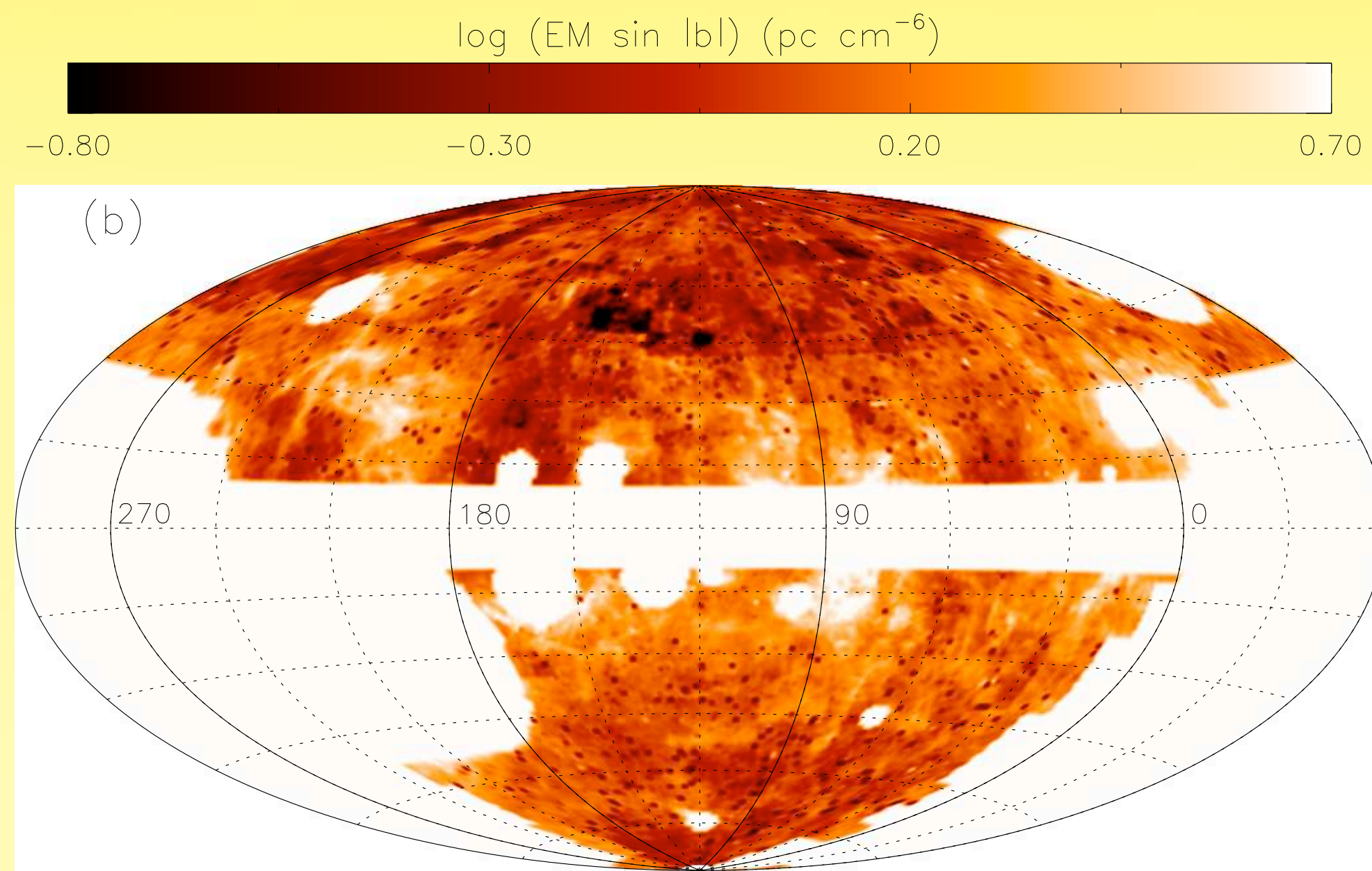


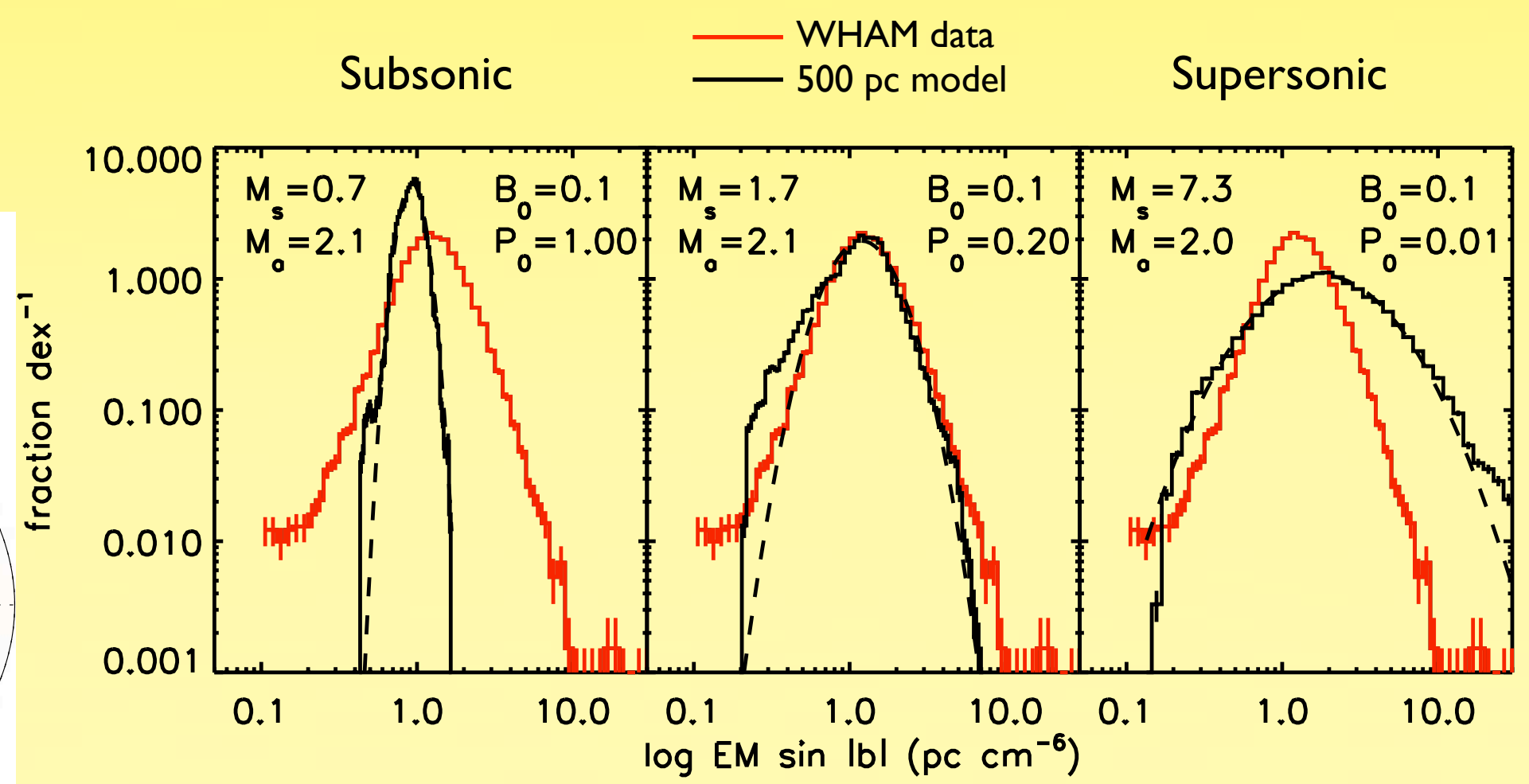
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## Abstract

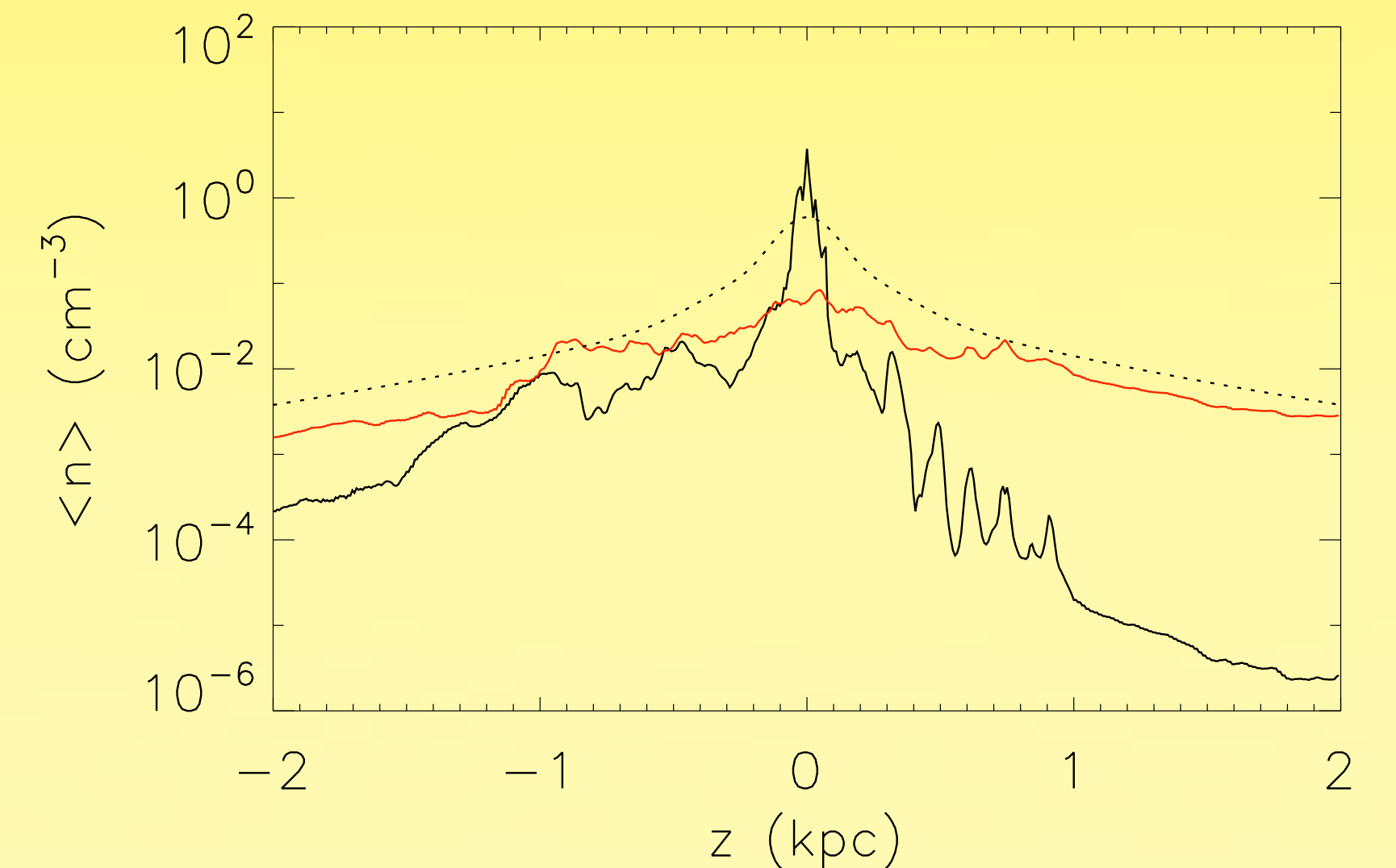
We address the long-standing question of the transport of the radiation responsible for maintaining the ionization of the warm ionized medium (WIM) in the context of a turbulent interstellar medium (ISM). Simple, single-fluid, isothermal magnetohydrodynamical simulations of a turbulent plasma reproduce the basic observed properties of the Galactic WIM. With that motivation, we have explored hydrodynamical simulations of a supernova-driven, turbulent, multiphase ISM in combination with photoionization modeling. We find that the turbulence creates enough low density paths for Lyman continuum photons to propagate from O stars near the midplane to WIM gas a kiloparsec above the plane. However, more gas is at heights  $< 1$  kpc than suggested by observations and the distribution of modeled emission measures is wider than observed. The addition of magnetic fields to the hydrodynamical simulations may address both inconsistencies.



**Figure 1: WHAM Northern Sky Survey of H $\alpha$  emission** with classical H II regions and  $|b| < 10^\circ$  sightlines removed.



**Figure 2: Probability distribution functions** of EM  $\sin |b|$  towards WIM sightlines (red line). The distribution is nearly lognormal. An isothermal, driven, mildly supersonic ( $M_s \approx 2$ ; center panel) turbulent MHD model with physical scales appropriate for the WIM (black line) approximately reproduces the observed distribution.



**Figure 4: Photoionization simulation mean density** as a function of height. Red line: mean electron density. Black line: mean neutral density. Dotted line: Dickey-Lockman density distribution with a low density, extended distribution of scale height 1000 pc for ionized hydrogen.

## Introduction

Warm ( $10^4$  K) photoionized gas pervades the interstellar medium of the Milky Way and other galaxies. This major component of the ISM, called the warm ionized medium (WIM) or diffuse ionized gas (DIG) consists of a turbulent layer with a scale height of 1–1.5 kpc (Gaensler et al 2008, Savage & Wakker 2009).

The ionization power requirement of the WIM is  $\sim 2 \times 10^4$  erg  $s^{-1} cm^{-2}$  in the Galactic disk (Reynolds 1990). This is comparable to the total kinetic energy input by supernovae or  $\approx 1/7$  of the Lyman continuum radiation from OB stars. Therefore, early-type stars are the only known source capable of maintaining the ionization of the WIM. However, the mechanism by which ionizing photons propagate from OB stars near the midplane to the WIM at  $|z| \approx 1$  kpc is not obvious, as neutral gas near the star could absorb most or all of the ionizing photons.

Ciardi et al (2002) showed that a 3D fractal structure in the ISM creates low-density paths which allow ionizing photons to propagate to large heights. Because such a fractal structure can be produced by turbulence, we investigate the photoionization of a supernova-driven, multiphase, turbulent ISM.

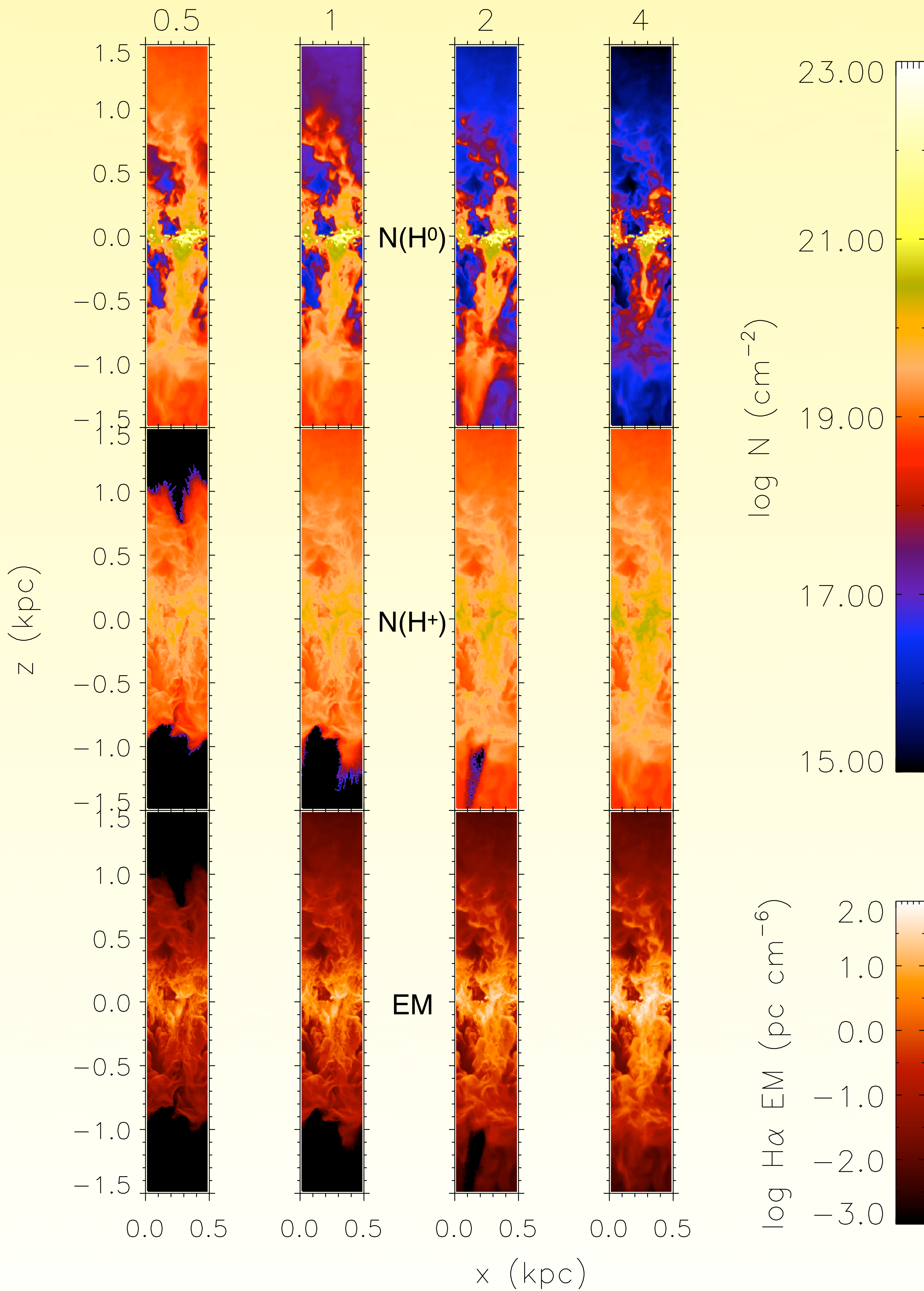
## WHAM Observations

We utilize the subset of the Wisconsin H-Alpha Mapper (WHAM) Northern Sky Survey (Haffner et al 2003; see also the talk by Matt Haffner at this meeting) presented by Hill et al (2008). We exclude sightlines which pass through large H II regions with an identified, local source of ionization to leave predominantly emission from the WIM. We also exclude low-latitude sightlines ( $|b| < 10^\circ$ ) to reduce the effects of extinction due to dust. These data are shown in Fig 1. A histogram of the H $\alpha$  emission measures from Fig 1 is shown in Fig 2; the distribution is approximately lognormal, suggestive of a density structure established by turbulence.

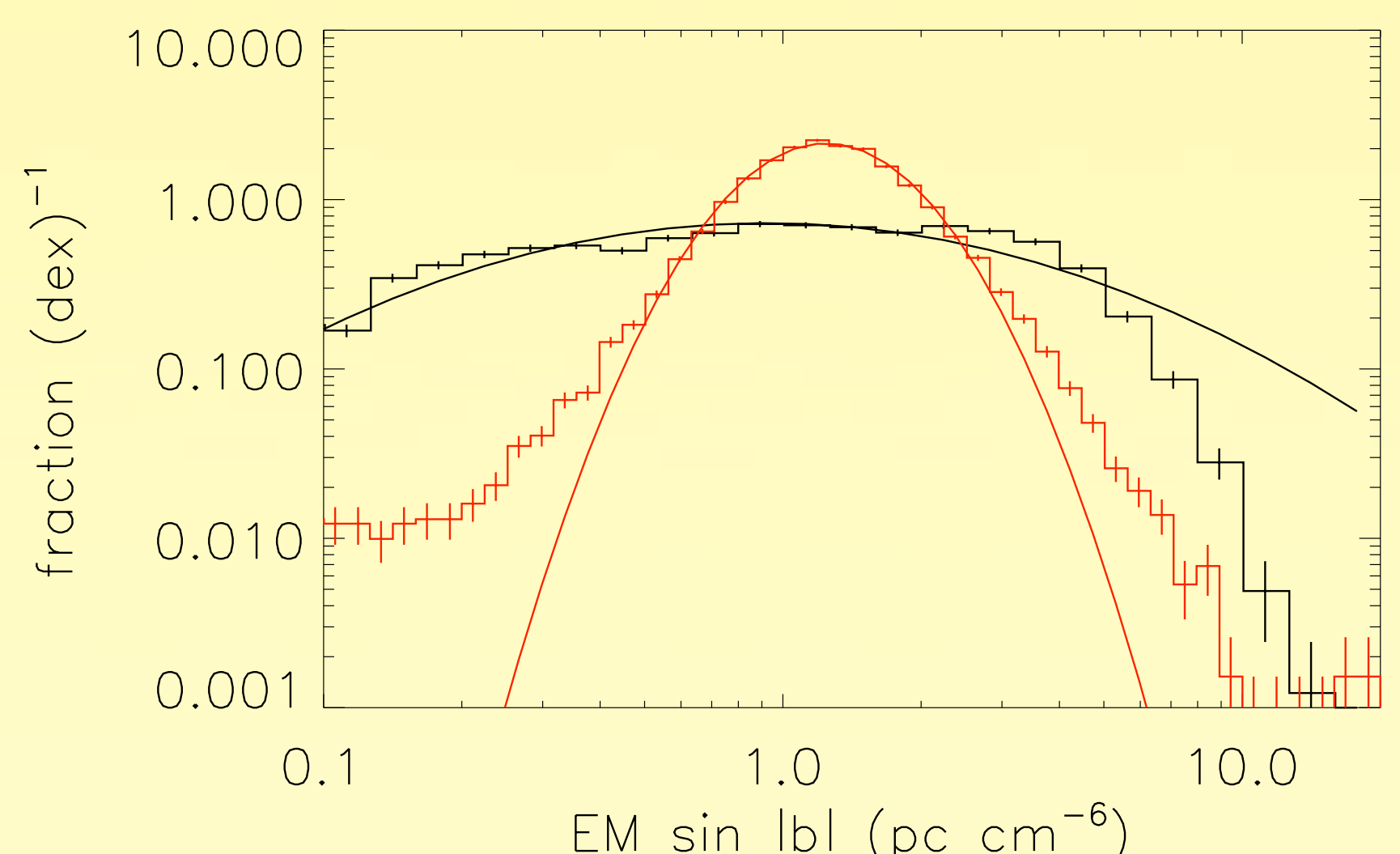
## Dynamical Simulations

**Isothermal simulations:** Kowal et al (2007) present simulations of 3D compressible, isothermal MHD turbulence over a range of sonic and Alfvénic Mach numbers. The turbulence is driven artificially with a driving scale one quarter the size of the initially-uniform box. The mildly supersonic runs of these simple simulations reproduce the essential features of the observed emission measure distribution (Figure 2; Hill et al 2008). This leads us to consider the WIM in the context of a realistic, multi-phase ISM.

**Supernova-driven simulations:** Joung et al (2006, 2009) have developed hydrodynamical simulations of a supernova-driven turbulent ISM. The simulations utilize the FLASH v. 2.4 code. The adaptive mesh resolution is  $\approx 2$  pc near the plane ( $|z| < 125$  pc).



**Figure 3: Photoionized supernova-driven simulations of the turbulent ISM** viewed edge on. Top panels: Column density of H $^0$ . Middle panels: Column density of H $^+$ . Bottom panels: H $\alpha$  EM =  $\int n_e^2 ds$ . Simulations with a total ionizing luminosity of 0.5, 1, 2, and  $4 \times 10^{49}$   $s^{-1}$  within the 0.5 kpc-square column of our simulation are shown (left to right). The two highest ionizing flux models fully ionize the WIM, as observed.



**Figure 5: Probability distribution functions of photoionization simulation** with  $Q = 2 \times 10^{49} s^{-1}$  (black histogram) compared to the WHAM data (red line). In the simulations, gas near the plane ( $|z| < 150$  pc) is not included because it primarily represents locally ionized gas. The model distribution is considerably wider than observed.

## Photoionization

To explore the photoionization of the WIM, we utilize a 3D Monte Carlo photoionization code (Wood et al 2000, 2004). We randomly place O stars within a realization of the supernova-driven simulations with a scale height of 63 pc and a surface density of 24 O stars  $kpc^{-2}$ . Like the hydrodynamical simulations, we use periodic boundary conditions on the sides of the box while outflow is allowed through the top of the box only.

## Conclusions

For total total ionizing luminosities of  $\geq 2 \times 10^{49} s^{-1}$ , we are able to fully ionize the WIM (Fig 3 and 4). This result is consistent with analytically produced fractal density structures and highlights the importance of dynamics for the existence of the WIM. **The result also underscores our expectation that O stars are the dominant source of the ionization of the WIM.**

However, the distribution of emission measures from the simulation is considerably wider than observed (Fig 5). The addition of magnetic fields (work in progress) to our dynamical simulations promises to address this disparity due to the reduced compressibility of the medium.

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The Dynamic ISM, Naramata, BC, June 2010