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Turbulent Mixing Layers in the Interstellar Medium of Galaxies

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We propose that turbulent mixing layers are common in the interstellar medium (ISM). Injection of kinetic energy into the ISM by supernovae and stellar winds, in combination with density and temperature inhomogeneities, results in shear flows. Such flows will become turbulent due to the high Reynolds number (low viscosity) of the ISM plasma. These turbulent boundary layers will be particularly interesting where the shear flow occurs at boundaries of hot ($\sim 10^6$K) and cold or warm (10^2– 10^4K) gas. Mixing will occur in such layers producing intermediate-temperature gas at $T \approx 10^{5.0-5.5}$ that radiates strongly in the optical, ultraviolet, and EUV.

Expanding on the ideas of Begelman & Fabian (1990), we have modeled these layers under the assumptions of rapid mixing down to the atomic level and steady flow. By including the effects of non-equilibrium ionization and self-photoionization of the gas as it cools after mixing, we predict the intensities of numerous optical, infrared, and ultraviolet emission lines, as well as absorption column densities of C IV, N V, Si IV, and O VI.

We obtain the following results:

1) All of the C IV λ1550 emission observed by Martin & Bowyer (1990) could be explained by mixing layers in the thick disk/low halo. To match the emission/absorption ratio, a pressure, $p/k_B \approx$ 2000–3000 cm^{-3} K, is required. If $\log \bar{T} = 5.3$ the models match the observed emission line ratio C IV/O III] λ1663 $\sim$ 2.

2) The observed absorption-line column densities of C IV, N V, Si IV and O VI can all be matched by mixing layer models with $\log \bar{T} =$ 5.0–5.3 if there is some grain depletion.

3) A significant contribution to the Hα background in the Galaxy could come from mixing layers between gas at 10^6 K and cold clouds at 10^2 K. The calculated optical line ratios of [N I] λ5201, [N II] λ6583, [O I] λ6300, [O III] λ5007 and [S II] λ6716 relative to Hα are close to the observed values.

4) Mixing layers with warm (10^4K) gas produce [S II] λ6716/H$\alpha \approx$ 0.3, in good agreement with observations of diffuse ionized gas in "interstellar froth" in Magellanic irregulars and some edge-on spirals and with the extended component of diffuse ionized gas in the Seyfert NGC 1068. Both the [N II] λ6583/Hα and the [O II] λ3727/[O III] are close to observed values as well.

5) The cooling time for hot gas is decreased by factors of 10–100 in mixing layers over quiescent cooling. This could be important for regulating the hot gas filling factor and could serve to quench galactic fountain activity. Some 20% of the supernova power in the Galaxy and 75 $M_\odot$ yr^{-1} may be processed through mixing layers.

Further observations of the emission lines O III] λ1663, [O III] λ5007 and O VI λ1032,1038 at high latitude are important to test our models and to understand the nature of "frothy" diffuse ionized gas in the ISM.

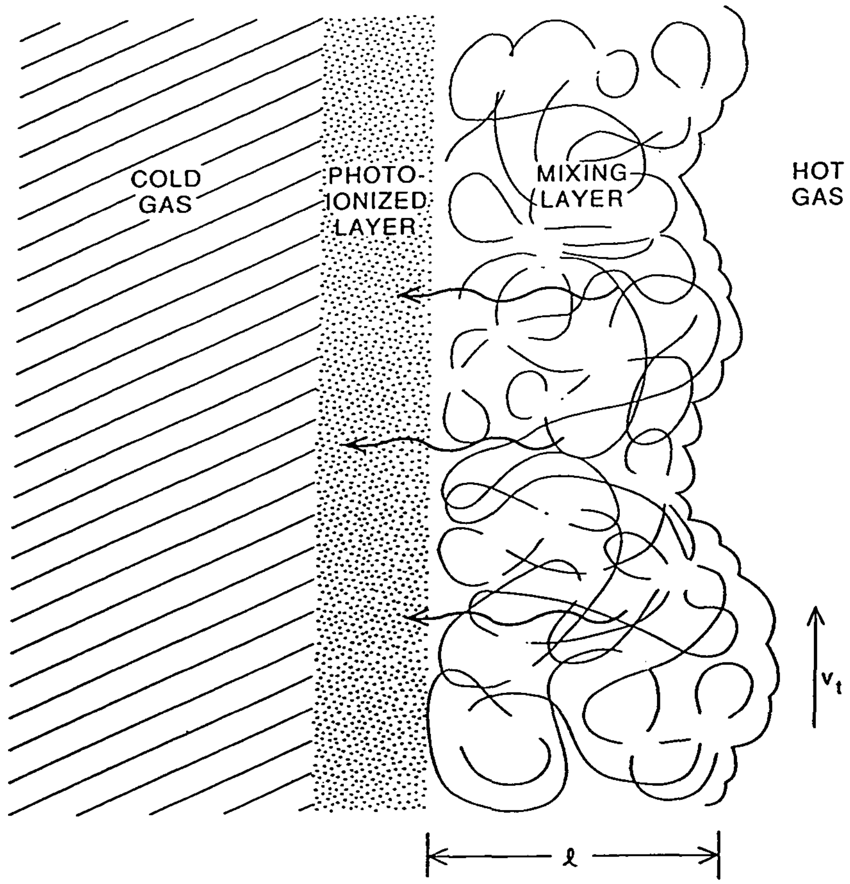

Fig. 1.—Schematic drawing of mixing-layer geometry, showing hot and cold gas and a photoionized layer abutting the mixing layer.

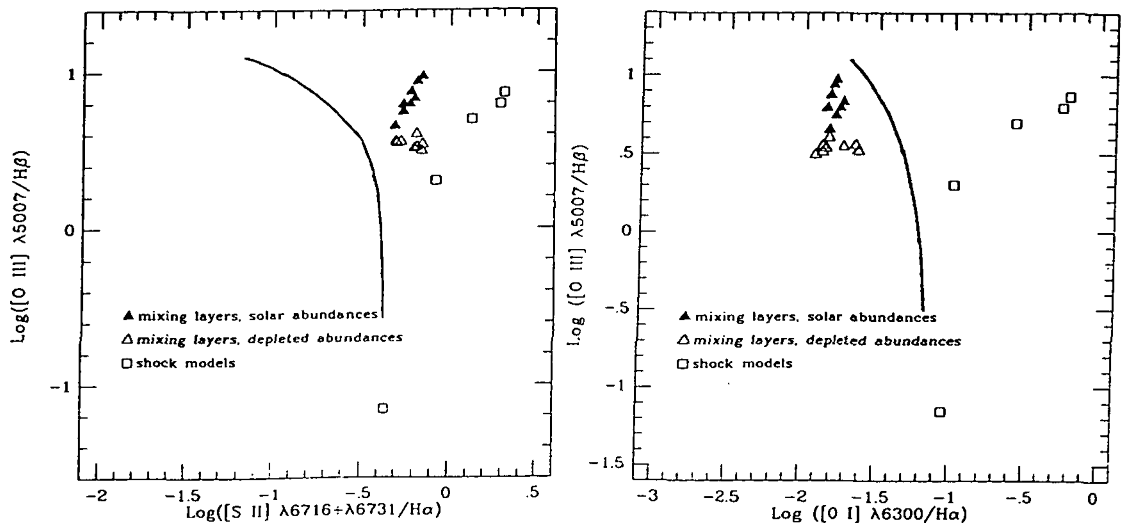

Fig. 2.—Emission line ratios in turbulent mixing layers with $\log \bar{T} = 5.5$ and 5.7 and in the shock models of Shull & McKee (1979, ApJ 227, 131) for shock velocities ranging from 80 to 130 km s^{-1}. The curve, from Osterbrock & Viellieux (1987, ApJS 63, 295), seperates AGN (upper right) from H II regions (lower left).