Compressive Structures in The Foreshock of Interplanetary Shocks

S. Raptis[1], D. Trotta[2], D. L. Turner[1], X. Blanco-Cano[3], T. Karlsson[4], H. Hietala[5], I. C. Jebaraj[6], A. Osmane[7], and L. B. Wilson III[8]

[1]*The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA*
[2]*European Space Agency (ESA), European Space Astronomy Centre (ESAC), Camino Bajo del Castillo s/n, 28692 Villanueva de la Cañada, Madrid, Spain*
[3]*Departamento de Ciencias Espaciales, Instituto de Geofísica, Universidad Nacional Autónoma de México, Mexico City, Mexico*
[4]*Division of Space and Plasma Physics - KTH Royal Institute of Technology, Stockholm, Sweden*
[5]*Department of Physics and Astronomy, Queen Mary University of London Mile End Road, London E1 4NS, UK*
[6]*Department of Physics and Astronomy, University of Turku, 20500 Turku, Finland*
[7]*Department of Physics, University of Helsinki, Helsinki, Finland*
[8]*NASA Goddard Space Flight Center, Greenbelt, MD, USA*

Abstract

Upstream of a supercritical quasi-parallel shock, a dynamically evolving foreshock environment emerges. In this region, reflected ions from the shock give rise to abundant Ultra Low Frequency (ULF) waves, which in turn strongly influence the system's dynamics. In most planetary settings, these waves as they approach the shock, they non-linearly evolve, steepen and form a variety of localized compressive structures, commonly referred to as shocklets or Short-Large Amplitude Magnetic Structures (SLAMS).

At interplanetary (IP) shocks, however, observations of such structures have been scarce, and the few reported cases have generally been attributed to pre-existing solar wind wave evolving due to the shock presence rather than to shock-generated waves as at planetary bow shocks.

Here, we use Solar Orbiter data to examine a strong quasi-parallel IP shock ($Ma > 5$), assessing both the presence of compressive structures in its foreshock and its broader foreshock characteristics. We then compare these results with those from a similarly quasi-parallel bow shock at Earth, of comparable Mach number, observed during the Dayside string-of-pearls MMS campaign in 2024–2025. This comparison reveals systematic differences that help us understand why localized compressive structures are more commonly observed at Earth than at IP shocks. Finally, we discuss the underlying physical mechanisms and their implications for shock structure and the downstream environment.