Imperial College London

Shock Waves with Solar Orbiter

Dylan Shepherd & Gabriel Maheson
Supervised by: Dr. Heli Hietala & Dr. Jonathan Eastwood
Space and Atmospheric Physics

1 Introduction

1.1 Solar Orbiter

Solar Orbiter will address questions such as: **how do Solar eruptions produce energetic particle radiation that fills the heliosphere?** Interplanetary shocks are capable of accelerating particles in the solar wind, and **our project aims to** analyse these shocks using the magnetic field data from Solar Orbiter.

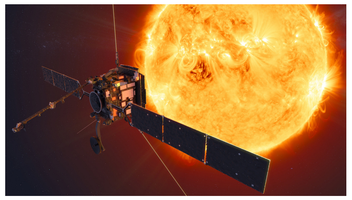

Fig.1 Artist's impressions of Solar Orbiter taken from [1].

1.2 Interplanetary shocks

These can occur when a coronal mass ejection from the sun meets the solar wind, or when two streams of solar wind emanating from the Sun with different velocities meet. We are interested in the obliquity (θ_{Bn}) of the shock, the frequencies, propagation directions (θ_{kB}) and polarisations of the waves, and type of waves produced by the shock.

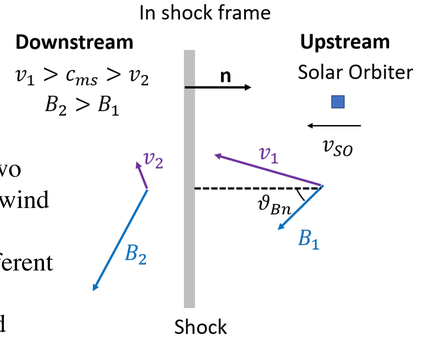

Fig.2 Diagram of shock in frame of the shock.

2 Research Questions

This study aimed to explore:

- **What are the properties of the interplanetary shocks we observe in the solar wind and their waves?**
- **Do these observations agree with current theory?**

3 Methodology

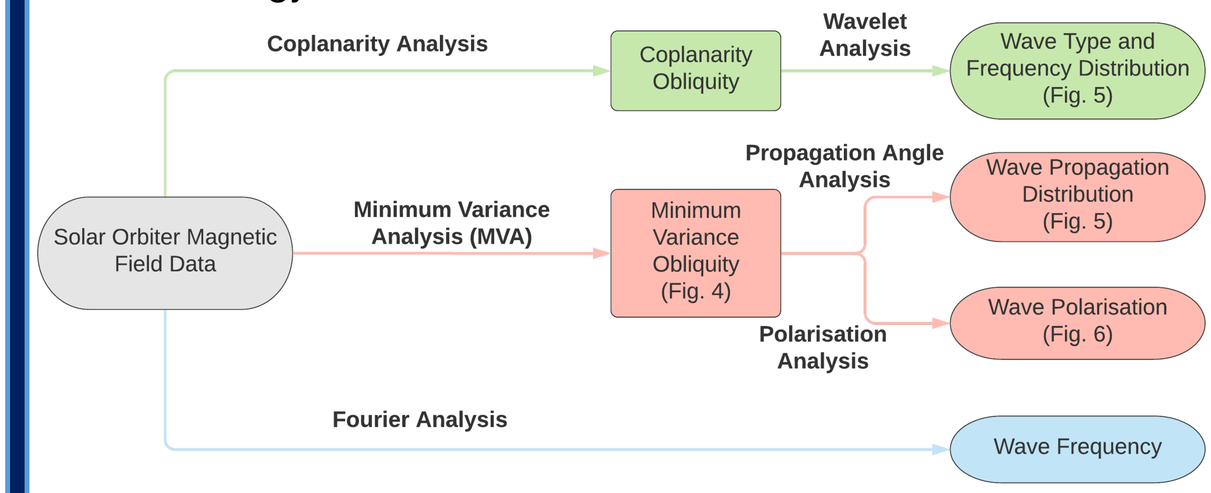

Fig.3 Flow chart showing methods developed in this project to analyse the shocks and their associated waves.

4 Analysis & Results

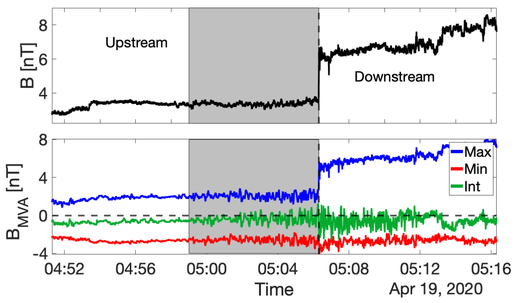

Fig.4 Plot of the magnetic field magnitude and MVA components for a quasi-parallel shock observed on 19th April 2020.

- Obliquity determined as **(46.4 ± 2.2) °** and **(42.0 ± 2.5) °** through coplanarity and MVA methods, respectively.
- Shock quasi-parallel. Extended foreshock like other observed quasi-parallel shocks [2].

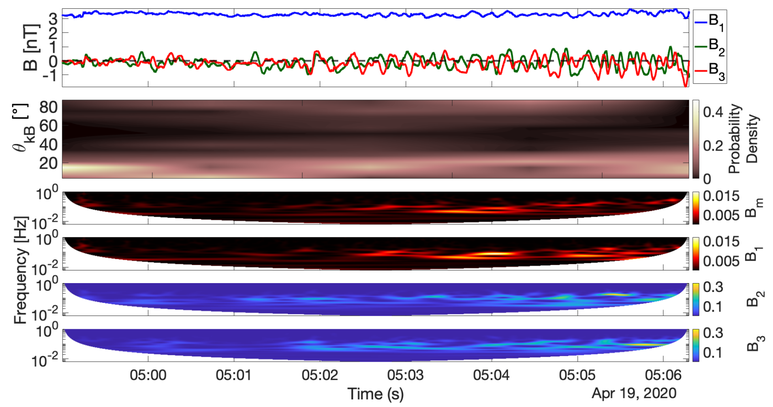

Fig.5 Plot of the magnetic field in compressive – transverse co-ordinates, wave propagation distribution, and wavelet transforms for the waves observed immediately upstream of the quasi-parallel April 19th shock.

- Wave propagation angle analysis tells us there are **mostly parallel propagating waves** upstream, with some **perpendicular propagating waves closer to the shock**.
- Wavelet analysis tells us there are **mostly transverse waves** upstream with frequencies in the range of **(0.026 – 0.165) Hz**, and **some compressive waves closer to the shock** with frequencies in the range of **(0.027 – 0.308) Hz**.
- Frequency ranges match that of other quasi-parallel shocks [3].

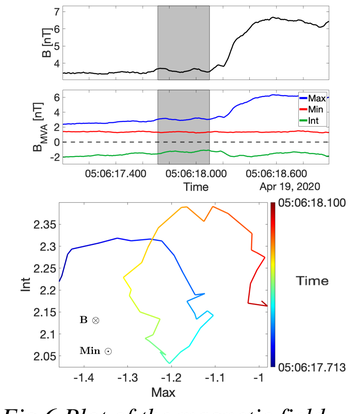

Fig.6 Plot of the magnetic field magnitude, MVA components, and associated component plot of precursor waves for April 19th shock.

- Fourier analysis of precursor waves gave its frequency as **(5.5 ± 1.3) Hz.**
- MVA analysis shows polarisation of wave is **right-handed** with respect to magnetic field, consistent with whistler waves [3].

5 Additional Shocks

This framework was applied to further shocks in 2020:

	Obliquity	Precursor Frequency	Precursor Polarisation
August 21st	**(65 ± 1) °**	**(2.8 ± 1.1) Hz**	Right-Handed
November 12th	**(70 ± 7) °**	**(1.1 ± 1.1) Hz**	Right-Handed

6 Conclusion

- Upstream of a quasi-parallel shock we observe right-handed ion-cyclotron waves, moving into compressive waves closer to the shock.
- Upstream of a quasi-perpendicular shocks we observe no extended foreshock but clearer whistler precursors.
- Beyond this project, the same analysis framework could be applied to new shocks as they are observed by Solar Orbiter.

References
[1] - Available at:<https://www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter/Solar_Orbiter_factsheet> [Accessed 25 February 2021].
[2] - Burgess, D. et. al., 2005. Quasi-parallel Shock Structure and Processes. *Space Science Reviews*, 118(1-4), pp.205-222.
[3] - Kan, J., Mandt, M. and Lyu, L., 1991. Quasi-parallel collisionless shocks. *Space Science Reviews*, 57(3-4), pp.201-236.

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