Foreshocks Across the Heliosphere: System Specific or Universal Physical Processes?

Abstract

The foreshock is a disturbed region upstream of supercritical shocks, formed by the interaction of reflected particles and the incident plasma. Foreshocks can strongly affect particle acceleration, and modify the solar wind before its interaction with magnetospheres or ionospheres downstream of the shock.

The research activities focusing on shocks near the Sun, Earth, and other planets have been the efforts of rather unconnected groups. Consequently, a systematic organization of the data obtained so far is lacking, which is why the following science question is still unsolved: ***How do foreshock processes change with system properties and upstream plasma parameters, across the solar system?***

In order to answer this question, we have collected a team of top-tier researchers within the field of shock and foreshock physics, active within different solar system environments. Together the team has the required comprehensive and complementary resources, including both readily available event lists and simulations. A systematic reorganization using the terrestrial foreshock as a benchmark (Figure 1) will enable us to disentangle interlinked dependencies between the system properties and upstream parameters, revealing their relative importance and universal trends.

A comprehensive investigation of foreshock processes provides a strong test of our current understanding, as well as predictions for shocks at objects currently beyond reach (such as exoplanets and astrophysical shocks). The timeliness of the proposal is underpinned by new data from the Jovian bow shock by Juno; the upcoming novel Parker Solar Probe observations of coronal shocks and interplanetary shocks close to the Sun; and the preparations for Solar Orbiter and BebiColombo.

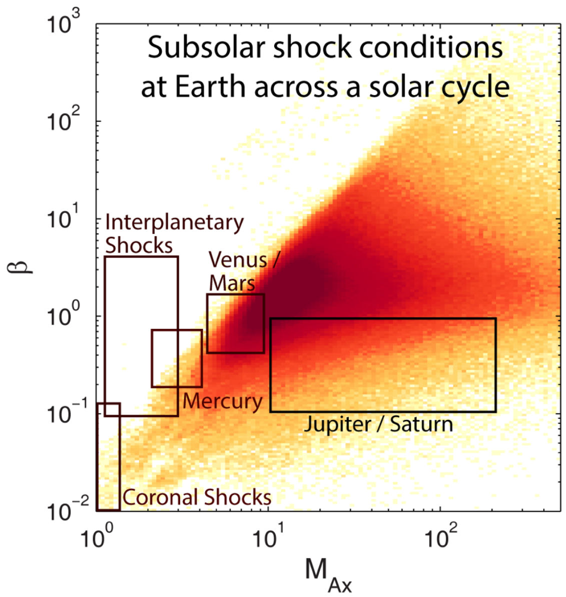

Figure 1 *Typical Alfvénic Mach numbers and plasma betas at various environments compared with the distribution at Earth from the OMNI database.*

1 Scientific rationale

1.1 Background

Shocks are ubiquitous throughout the universe. There are three main (dimensionless) parameters which locally characterize a shock: the Mach number, plasma beta, and the angle θ_{Bn} between the shock normal and upstream magnetic field. Their typical values vary throughout the heliosphere leading to different environments occupying different regions in parameter space (Figure 1). If the Mach number is large enough, a part of the incoming particles (ions) is reflected and the shock is called supercritical [Kennel et al., 1985]. In a planar shock geometry, these reflected particles behave differently depending on the shock obliquity: If θ_{Bn} is large (i.e., the shock is **quasi-perpendicular**) the reflected particles will gyrate back into the shock. If the shock is **quasi-parallel**, the reflected particles can escape upstream and interact with the incident plasma over long distances. Most shocks in the heliosphere are supercritical. Some interplanetary and most coronal shocks tend to be subcritical on global scales, but this behavior may vary on smaller scales.

The upstream region magnetically connected to the shock and filled with reflected particles and associated waves is called **the foreshock.** Figure 2 shows the Earth's foreshock as an example of a planetary foreshock, of which we also have most of the observations. As noted by Kennel et al. [1984], the radius of curvature of the terrestrial bow shock is smaller than the scale of its foreshock, leading to an interplay between quasi-perpendicular (top) and quasi-parallel (bottom) shock regions, which may not be present at more extended shocks. Still, **many foreshock phenomena observed at Earth have also been reported also at other solar system shocks** (see Annex I, Table 1).

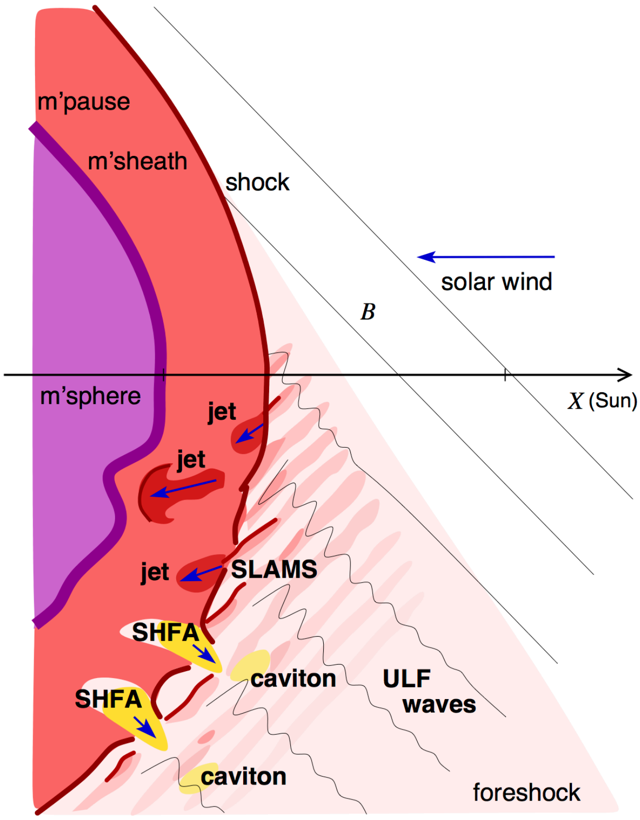

Figure 2 *Sketch illustrating different structures near the terrestrial bow shock.*

The interaction of the back-streaming ions (pink shading) with the incident solar wind leads to generation of waves, most notably ultra-low frequency waves (**ULFs**), with periods of ~30 seconds near Earth [Wilson, 2016]. When the waves convect back to the shock, they steepen and undergo nonlinear interactions with themselves, the ions, and locally generated waves, forming structures. These structures include, but are not limited to, short large amplitude magnetic structures (**SLAMS;** [Schwartz and Burgess, 1991]) and **cavitons** (localized regions of low density and low magnetic field [Blanco-Cano et al., 2009]; yellow). When cavitons reach the bow shock, they may disrupt it, causing small spontaneous hot flow anomalies (**SHFAs**; [Zhang et al., 2013]) with sunward flows. Larger scale transient concentrations of hot ions, called Hot Flow Anomalies (**HFAs**; [Burgess, 1989; Thomas et al., 1991]) and Foreshock Bubbles (**FBs**; [Omidi et al., 2010; Turner et al., 2013]) are caused by sharp changes in the interplanetary magnetic field (**IMF discontinuities**).

Foreshock processes provide a challenge and a testbed for our understanding of fundamental plasma physics. Foreshock phenomena also affect the shock's ability to accelerate particles - one of the main factors underpinning the importance of space plasma shocks. Furthermore, foreshock-related structures such as **jets** can significantly affect the region downstream of the shock, perturbing magnetospheres and ionospheres [Plaschke et al., 2018]. At Earth, effects of foreshock processes are felt all the way to the ground [Regi et al., 2014].

1.2 Science question

The research activities focusing on shocks near the Sun, Earth, and other planets have been the efforts of rather unconnected groups. Consequently, the following science question is still unsolved:

How do foreshock processes change with system properties and upstream plasma parameters, across the solar system?

While databases and some results for different environments exists (see Annex I, Table 1), a systematic collection and reorganization of the data is required to **disentangle interlinked dependencies between the system properties and upstream parameters:** as a notable example, the size of planetary bow shocks increases with the heliocentric distance, as does the solar wind Mach number. I.e., Saturn's bow shock has both a larger radius of curvature and a higher Mach number than Mercury's. **Examples of specific research questions on the relative importance of universal vs system specific processes include:**

- How do the properties (e.g., size, compressivity) of foreshock structures scale with upstream Mach number and system size?

  A scaling study by Valek et al. [2017] compared **Hot Flow Anomalies** observed at Mercury, Venus, Earth, Mars, Jupiter, and Saturn, and showed that their size scales with the size of the planetary bow shock. However, Mach number also increases with roughly the same order and thus may too affect HFA sizes. Similarly, the existence of **SLAMS** has been established for Venus, Mars, Jupiter, and Saturn [Tsurutani et al., 1993a, 1993b; Bertucci et al., 2007; Collinson et al., 2012; Masters et al., 2013], yet they don't seem to form at Mercury [Sundberg et al., 2013; Karlsson et al., 2016]. It is unknown if this is due to weaker shock conditions at Mercury or because the size of SLAMS becomes larger than the extent of the entire quasi-parallel shock.
- How does particle acceleration change with Mach number, shock obliquity, and system size?

  If the system size is small, then reflected ions and waves swept back towards the shock by the solar wind will affect shock segments with much lower θ_{Bn} values than their point of origin. Krauss-Varban et al. [2008] suggested, based on hybrid simulations, that larger shocks such as IP shocks and the

Kronian bow shock, could therefore have foreshock regions upstream of **larger θ_{Bn} values** than the terrestrial bow shock. However, this simulation prediction has not yet been investigated.

Quasi-parallel shocks have often been considered to be less efficient particle accelerators than quasi-perpendicular ones [Lee et al., 2012]. However, Turner et al. [2018], and Liu et al. [2017a,b] show that discontinuity-driven large **foreshock transients** (HFAs, FBs) can locally accelerate ions and electrons to MeV energies at Earth. Also at Saturn, under higher **Mach number** conditions, quasi-parallel shock regions with **structures like SLAMS** can efficiently accelerate electrons up to relativistic energies [Masters et al., 2013]. Yet, the relative importance of upstream properties (Mach number, shock obliquity), system size, and corresponding changes in foreshock structures are still unclear.

- How do ion composition effects change foreshock processes?

  Comparisons of different Solar System environments must consider system specific ion compositions: Planetary shocks of induced magnetospheres are usually located **within their neutral exospheres**. As a result, solar wind reflected particles interact with neutral and charged particles of exospheric origin, as observed at Mars [Mazelle et al., 2018]. Additionally, waves generated by pick up of newborn ions coexist with foreshock waves [e.g., Shan et al., 2016]. Voyager measurements suggest that the termination shock is **"mediated" by hot pick-up ions** [e.g., Zieger et al., 2015, and references therein]. At low-activity comets (e.g., 67P/Churyumov-Gerasimenko), **finite gyroradius effects** may create an asymmetric bow shock [e.g., Rubin et al., 2015].

Disentangling interlinked dependencies requires a system of reference. We now have a wide range of observations upstream of Earth's bow shock that allow us to sample upstream parameters typical of other environments (see Figure 1). Furthermore, while global numerical simulations resolving foreshock dynamics remain computationally expensive, a multitude of global simulation runs already exist under different conditions (see Annex I). These available observations and simulations now give us an opportunity to answer the overarching science question.

1.3 Methods

Links between foreshocks to date have been heuristic. In our team of top-tier scientists, we will make comprehensive, systematic, and quantitative comparisons, covering a wide parameter space. We will proceed in the following manner, also illustrated in Figure 3:

1) We will **collate** the characteristics of solar system environments under which foreshock phenomena/processes have been recorded, using readily available event lists (Annex I). We will consider both the global foreshock regions as well as waves and non-linear structures within them, using a combination of in-situ and remote-sensing observations (where appropriate) as well as simulations to ascertain plasma and field parameters.
2) We will then analyze the phenomena using two complementary approaches:
   a. We will investigate how the key properties of the foreshock phenomena change as functions of **upstream parameters.** Observations of the same phenomenon from different environments will be plotted together to reveal universal trends. Deviations thereof indicate system specific processes. Conclusions will be tested against system comparisons (2b).
   b. We will divide foreshock observations from Earth into benchmark subsets matching the upstream parameters of other solar system environments (Figure 1). Comparing foreshock measurements at different environments under the same conditions will reveal whether key properties are the same due to universal physical processes or vary as functions of relevant **system parameters**. These results will increase confidence in universal trends (2a).
3) Closure: We will publish results in articles, and in organized databases in a review/report.

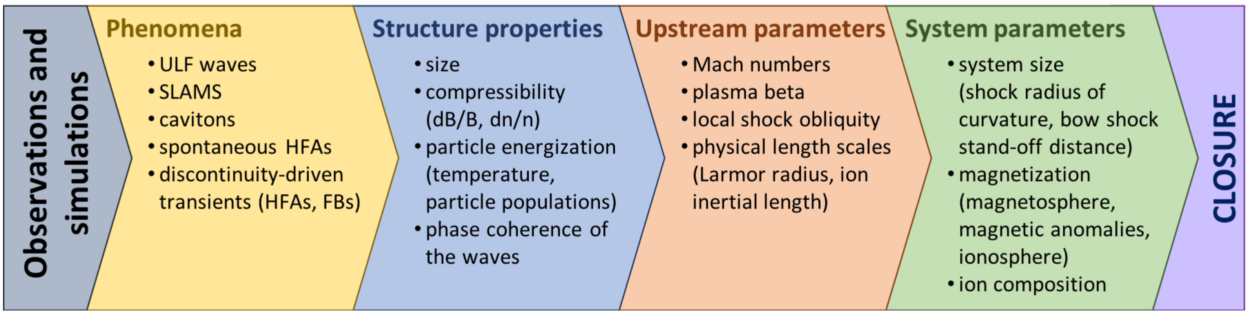

Figure 3 *Workflow of the project.*

For **example** (Figure 3), we will consider **Short Large Amplitude Magnetic Structures** (SLAMS), which have been reported at Earth, Venus, Mars, Jupiter, Saturn, comets, and interplanetary shocks. We will analyze how **compressive** they are as a function of **upstream Mach number**. For a fixed Mach number range, we will consider whether the compressibility depends on the **system size**. Simulations will allow us to further verify how the compressibility depends on the evolutionary stage of the SLAMS for fixed upstream conditions, providing an estimate of the uncertainty of single-spacecraft measurements.

1.4 Impact

1) **The systematic comparisons conducted in the proposed project will reveal the features of foreshock processes that are system specific as well as the universal and unifying factors.**
2) The identified parameter dependencies will serve as **inputs** for future theoretical and numerical shock (acceleration) **models**, as well as give **predictions** for currently non-accessible shocks (astrophysical shocks, exoplanets).
3) Parameter dependencies also give testable predictions for the **downstream impacts** of foreshock structures on their respective environments, paving the way to assess their effects on, e.g., planetary magnetospheres and ionospheres.
4) While shocks can be studied using a **combination of remote-sensing and in-situ measurements** in certain Solar System environments, only remote-sensing observations are available for shocks very close to the Sun and outside the Solar System. However, missions such as Parker Solar Probe and the upcoming Solar Orbiter will enable a connection to be made between these different regimes. Taking steps during the proposed project towards identifying the optimal parameters that may be used to relate remote-sensing and in-situ observations of shocks (such as variations in elemental abundance and radio signatures) is therefore an important element contributing to the success of those missions. This would then pave the way for clear future comparisons between solar-terrestrial and astrophysical shocks.

1.5 Timeliness

1) The timeliness of this proposal stems from **recent high-impact results** on the role of foreshock transients in accelerating particles [Turner et al., 2018; Liu et al., 2017a,b], as well as on the magnetospheric and ionospheric impacts of foreshock-generated structures [Archer et al., 2019; Collinson et al., 2018]. **Understanding these effects requires knowledge of how foreshock processes change as a function of upstream and system parameters**.
2) The proposed team effort is facilitated by (i) **the immense pool of terrestrial foreshock observations** by multi-spacecraft missions that are now available, and by (ii) **data from new missions**. E.g., the MAVEN data from Mars and the Juno observations of the Jovian bow shock have just become available [Hospodarsky et al., 2017]. Furthermore, Parker Solar Probe is on its journey approaching the Sun, where it is expected to make ground-breaking measurements of IP shocks in the outermost parts of the solar corona. First publicly available observations from this mission are expected by the end of this year, just in time to contribute to the proposed endeavor.
3) The results of the team are expected to **set the stage for future studies of foreshock regions by upcoming missions**. E.g., the recently launched BepiColombo mission consisting of two spacecraft will be inserted into Mercury-bound orbits in late 2025 after multiple flybys, and the Solar Orbiter mission will join Parker Solar Probe in 2020 to study the inner-heliosphere.

2 ISSI added value

ISSI would provide us with a chance to bring together people from very different scientific communities who can all contribute to our joint goals, but who would not otherwise have the opportunity for such a sustained collaboration. Given the differences between instruments on different missions, comparison and combination of datasets from different sources require close interaction between experts. These interactions are best conducted in face-to-face meetings at ISSI-Bern.

3 Confirmed team members

In order to achieve our objectives, we bring together a strong, multi-disciplinary team comprised of **11 core members from 8 countries**. Our combined expertise covers all relevant shock environments in the Solar System, observations and simulations, in situ and remote measurements. The pre-existing collaborations among some team members indicate that the working atmosphere will be productive and efficient. Our team is, hence, in a unique position to achieve the proposed goals.

	Name	Country	Role	Solar System environment	Phenomena
1	**Heli Hietala**	UK	team leader	Earth, IP shocks	shock structure, particle acceleration
2	**Ferdinand Plaschke**	Austria	co-leader	Earth	ULFs
3	**Martin Archer**	UK	member	Earth	ULFs, FBs, HFAs
4	**Markus Battarbee**	Finland	member	Earth, solar corona	shock and foreshock structure, particle acceleration
5	**Cesar Bertucci**	Argentina	member	Titan, Saturn, Mars, comets	shocks and discontinuities
6	**Xochitl Blanco-Cano**	Mexico	member	IP shocks, Earth, Mercury	foreshock waves and structures
7	**Glyn Collinson**	USA	member	Venus, Mars	HFAs, SHFAs, SLAMS
8	**Tomas Karlsson**	Sweden	member	Mercury, Earth, Saturn, comets	SLAMS, energetic ions
9	**David Long**	UK	member	solar corona	shock structure, particle acceleration
10	**Merav Opher**	USA	member	termination shock, heliosheath	shock structure
11	**Nick Sergis**	Greece	member	Saturn, Jupiter	particle acceleration, magnetospheric ion leakage, shock structures
	Terry Zixu Liu	USA	early-career scientist	Earth	HFAs, FBs, particle acceleration
	Rami Vainio	Finland	external member providing Monte Carlo simulations	solar corona, IP shocks	Solar Energetic Particles, shock acceleration
		Color code:	*in situ observer*	*remote observer*	*modeler*

4 Schedule of the project

We propose to meet two times at the ISSI facilities in Bern.

- Pre-meeting
  - Collate a joint inventory from datasets/literature of phenomena, their properties, and the upstream parameters
- First meeting (winter 2019; one week)
  - Search observations at Earth for events with matching upstream conditions to those at the other environments (taken from inventory)
  - Determine most relevant phenomena, properties, and universal/system parameter ranges to focus upon through initial analyses and discussions
  - Write outlines for papers and assign further analysis tasks
- Second meeting (winter 2020; one week)
  - Discuss analyses, make conclusions
  - Compile final databases for publication
  - Provide final input to draft research papers

Between the meetings we will hold regular teleconferences to monitor and discuss the progress.

5 List of the expected outputs

- Databases and documentation in review paper format for long-lasting impact.
- Research papers on: (i) comparative physics at different environments; (ii) scaling throughout the heliosphere; and (iii) system specific aspects.

6 Facilities and financial support requested

We are happy with the usual facilities ISSI provides and don't have special requests. We request the standard financial package for international teams. This will cover the hotel and subsistence costs for all team members for two one-week meetings at ISSI, and the travel costs of the team leader (500-600 eur/meeting). We would also request hotel and subsistence costs for early-career scientists (to be invited if the proposal is selected) – these will not exceed 20% of the funds allotted to the team.

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Turner, D. L., N. Omidi, D. G. Sibeck, and V. Angelopoulos (2013), First observations of foreshock bubbles upstream of Earth's bow shock: Characteristics and comparisons to HFAs, J. Geophys. Res., 118, 4, 1552–1570, doi:10.1002/jgra.50198.

Turner, D. L., L. B. Wilson III, **T. Z. Liu**, I. J. Cohen, S. J. Schwartz, A. Osmane, J. F. Fennell, J. H. Clemmons, J. B. Blake, J. Westlake, B. H. Mauk, A. N. Jaynes, T. Leonard, D. N. Baker, R. J. Strangeway, C. T. Russell, D. J. Gershman, L. Avanov, B. L. Giles, R. B. Torbert, J. Broll, R. G. Gomez, S. A. Fuselier, and J. L. Burch (2018), Nature, 561, 7722, 206–210, doi:10.1038/s41586-018-0472-9.

Valek, P. W., M. F. Thomsen, F. Allegrini, F. Bagenal, S. Bolton, J. Connerney, R. W. Ebert, R. Gladstone, W. S. Kurth, S. Levin, P. Louarn, B. Mauk, D. J. McComas, C. Pollock, M. Reno, J. R. Szalay, S. Weidner, and R. J. Wilson (2017), Hot flow anomaly observed at Jupiter's bow shock, Geophys. Res. Lett., 44, 16, 8107–8112, doi:10.1002/2017GL073175.

Wilson, L. B. III (2016), Low Frequency Waves at and Upstream of Collisionless Shocks, Geoph. Monog. Series, 216, 269–291, doi:10.1002/9781119055006.ch16.

Zhang, H., D. G. Sibeck, Q.-G. Zong, N. Omidi, D. Turner, and L. B. N. Clausen (2013), Spontaneous hot flow anomalies at quasi-parallel shocks: 1. Observations, J. Geophys. Res., 118, 6, 3357–3363, doi:10.1002/jgra.50376.

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Annex I: Resources of the team

The team members are part of the mission and instrument teams of all the key missions we will be using data from, and have expertise and access to the relevant tools. Examples of readily available events lists and existing simulation runs are given below. Table 1 shows the results of a preliminary literature review regarding reported observations of different foreshock phenomena in different heliospheric environments.

Event lists

- List of Earth's foreshock caviton events (92) in Kajdic, Blanco-Cano, et al. [2013].
- List of Earth's foreshock SHFA events (17) in Kajdic, Blanco-Cano, et al. [2017].
- GEM Focus Group on "Transient Phenomena at the Magnetopause and Bow Shock and Their Ground Signatures" website:
  - a list of Earth HFAs
  - a list of Earth Foreshock Bubbles
- List of IP shock SLAMS candidate events
- List of Venus SLAMS events
- List of Venus HFA events
- Venus SHFA event
- Mars HFA event
- Mars SHFA event
- List of Saturnian bow shock crossings by Cassini
- List of Saturn HFA events
- **CorPITA database** of global coronal shock waves measured using an automated approach applied to Extreme UltraViolet (EUV) observations
- **IPshocks.fi database** of 2200+ interplanetary shocks and their properties observed by ACE, Wind, STEREO, Helios, Ulysses, Cluster, DSCOVR, and the Voyagers
- **STEREO IP shocks database**, includes shock properties plus some information related to existence of ULF waves in their foreshocks

Publicly available databases

- **OMNI database** of solar wind conditions lagged to Earth's bow shock nose
- **Planetary Data System (PDS)** of general data from planetary missions such as MESSENGER, Cassini, Rosetta, etc.
- The **Michigan Solar Wind Model** (mSWiM) calculates solar wind conditions at a range of solar system objects by propagating measurements from near Earth orbiting spacecraft radially outwards with a 1-D MHD model. The output of the model is freely available.

Existing simulation runs

- **HYPERS** hybrid-Particle-in-Cell global 3D simulation run, magnetopause stand-off distance ⅓-½ of the Earth's magnetosphere, M_A = 10, plasma beta = 2.8, IMF cone angle of 21.6 degrees.
- **Vlasiator** hybrid-vlasov simulation runs of the Earth's foreshock, 2D-3V (2D spatial domain, 3D velocity space, Palmroth et al. [2018]):
  - 5-, 30- or 45-degree IMF inclinations
  - M_A=3.4, 5, 6.9, or 10
  - ß=0.17, 0.57, 0.69 or 2.3
  - Select runs have alpha particles as well as protons
- Global hybrid-Particle-in-Cell 2.5D simulation (N. Omidi's code, see Omidi et al. [2005]; Blanco-Cano et al. [2006]). Runs of the Earth's foreshock-bow shock system, M_A = 5, 8,12; ß = 0.5; IMF cone angle of 0, 45, 90 degrees.

	coronal shocks	interplanetary shocks	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Titan	comets	termination shock
ULFs	?	yes	yes	yes	yes	yes	yes	yes	?	yes	?
SLAMS	?	very rare	no?	yes	yes	yes?	yes?	yes	?	yes	?
SHFAs	?	?	?	yes	yes	yes	?	?	yes?	?	?
HFAs	?	?	yes?	yes	yes	yes	yes	yes	?	?	?
FBs	?	?	?	?	yes	?	?	?	?	?	?

yes	definite observations	very rare	studies indicate that they are very rare
yes?	probably do exist / suggestive observations	no?	studies indicate that probably don't exist
rare	studies suggest that they are rare	?	true knowledge gap

Table 1. *Occurrence of foreshock structures at different Solar System shock environments.*

HIETALA, Heli

Space and Atmospheric Physics Group, Imperial College, London, UNITED KINGDOM

Role in the project: leader, expertise on shock structure and particle acceleration, in-situ observations and observation-simulation comparisons

Current position:

- (7/2019 →) Royal Society University Research Fellow, Imperial College London, UK
- Junior Group Leader / Research Fellow, University of Turku, FINLAND
- Associate Researcher, University of California, Los Angeles, USA

Former Position(s):

9/2015-6/2018 Assistant Researcher, University of California, Los Angeles, USA

8/2012-9/2015 Postdoctoral Research Associate, Imperial College London, UK

Education:

PhD, theoretical physics, University of Helsinki, Finland, 2012

MSc, theoretical physics, University of Helsinki, Finland, 2007

Services in National and/or International Committees (last ones):

- Official representative of Finland, scientific commission H (*Waves in Plasmas*) of the International Union of Radio Science (URSI), 2018 – 2019
- Member of the *Waves in Plasmas* scientific commission of the Finnish National Committee of the International Union of Radio Science (URSI), 2014 – 2018
- Reviewer, NASA Heliophysics Supporting Research proposals, 2018

Honors:

- Lead-proposer and co-chair of the GEM Focus Group *Dayside kinetic processes in global solar wind-magnetosphere interaction*, 2016-2020
- Co-leader (with F. Plaschke) of the ISSI International Team 350 on *Jets Downstream of Collisionless Shocks*, 2015-2017
- Outstanding contribution to the Cluster and Double Star missions, ESA 2015
- Co-Investigator of the global hybrid-Vlasov simulation model *Vlasiator* developed at the Finnish Meteorological Institute, 2012 - present
- Outstanding Student Paper Award, Space Physics & Aeronomy, AGU 2011
- Outstanding Student Poster Award, Solar-Terrestrial Sciences, EGU 2011

Selected Publications (from 50):

1. **Hietala, H.**, Phan, T. D., Angelopoulos, V., Oieroset, M., Archer, M. O., Karlsson, T., and Plaschke, F., *In situ observations of a magnetosheath high-speed jet triggering magnetopause reconnection*. Geophys. Res. Lett., 45, (2018) doi:10.1002/2017GL076525
2. P. Kajdic, **H. Hietala**, and X. Blanco-Cano, *Different types of ion populations upstream of the 8 October 2013 interplanetary shock*, ApJL, 849 (2017) L27 doi:10.3847/2041-8213/aa94c6
3. T. Z. Liu, V. Angelopoulos, **H. Hietala**, and L. B. Wilson III, *Statistical study of particle acceleration in the core of foreshock transients*, J. Geophys. Res., 122, (2017) 7197–7208, doi:10.1002/2017JA024043. ***Editor's Highlight - 11 July 2017***

4. S. Dorfman, **H. Hietala**, P. Astfalk, and V. Angelopoulos, *Growth rate measurement of ULF waves in the ion foreshock*, Geophys. Res. Lett., 44, (2017) 2120–2128, doi:10.1002/2017GL072692. ***APS/DPP press release***

5. Y. Pfau-Kempf, **H. Hietala**, S. E. Milan, L. Juusola, S. Hoilijoki, U. Ganse, S. von Alfthan, and M. Palmroth, *Evidence for transient, local ion foreshocks caused by dayside magnetopause reconnection*, Ann. Geophys., 34, (2016) 943-959, doi:10.5194/angeo-34-943-2016

6. T. Z. Liu, **H. Hietala**, V. Angelopoulos, D. L. Turner, *Observations of a new foreshock region upstream of a foreshock bubble's shock*, Geophys. Res. Lett., 43, (2016) doi:10.1002/2016GL068984. ***Geophys. Res. Lett. cover image*** ***THEMIS Mission Research Highlight - 20 June, 2016***

7. M. Palmroth, M. Archer, R. Vainio, **H. Hietala**, Y. Pfau-Kempf, S. Hoilijoki, O. Hannuksela, U. Ganse, A. Sandroos, S. von Alfthan, J. P. Eastwood, *ULF foreshock under radial IMF: THEMIS observations and global kinetic simulation Vlasiator results compared*, J. Geophys. Res. Space Physics, 120, (2015) 8782–8798, doi:10.1002/2015JA021526

8. **H. Hietala** and F. Plaschke, *On the generation of magnetosheath high speed jets by bow shock ripples*, J. Geophys. Res., 118 (2013) 7237-7245, doi:10.1002/2013JA019172

9. E.K.J. Kilpua, **H. Hietala**, H.E.J. Koskinen, D. Fontaine, and L. Turc, *Magnetic field and dynamic pressure ULF fluctuations in coronal-mass-ejection-driven sheath regions*, Ann. Geophys., 31 (2013) 1559-1567, doi:10.5194/angeo-31-1559-2013

10. **H. Hietala**, A. Sandroos, and R. Vainio, *Particle Acceleration in Shock-Shock Interaction: Model to Data Comparison*, Ap. J. Lett., 751 (2012) L14, doi:10.1088/2041-8205/751/1/L14

11. **H. Hietala**, N. Partamies, T. V. Laitinen, L. B. N. Clausen, G. Facskó, A. Vaivads, H. E. J. Koskinen, I. Dandouras, H. Rème, and E. A. Lucek, *Supermagnetosonic subsolar magnetosheath jets and their effects: from the solar wind to the ionospheric convection*, Ann. Geophys., 30 (2012) 33-48, doi:10.5194/angeo-30-33-2012

12. **H. Hietala**, N. Agueda, K. Andréeová, R. Vainio, S. Nylund, E. K. J. Kilpua and H. E. J. Koskinen, *In situ observations of particle acceleration in shock-shock interaction*, J. Geophys. Res., 116 (2011) A10105, doi:10.1029/2011JA016669

13. **H. Hietala**, T. V. Laitinen, K. Andréeová, R. Vainio, A. Vaivads, M. Palmroth, T. I. Pulkkinen, H. E. J. Koskinen, E. A. Lucek and H. Rème, *Supermagnetosonic Jets behind a Collisionless Quasiparallel Shock*, Phys. Rev. Lett., 103 (2009) 245001, doi:10.1103/PhysRevLett.103.245001 ***ESA Science highlight 2010-April-23***

PLASCHKE, Ferdinand

Space Research Institute, Austrian Academy of Sciences, Graz, AUSTRIA

Role in the project: co-leader, expertise on jets, magnetopause motion, waves, and multi-point techniques

Current Positions:

- Since 2018: Researcher, Space Research Institute, Austrian Academy of Sciences, Graz, Austria
- Since 2014: External Lecturer, Graz University of Technology, Austria
- Since 2013: External Lecturer, University of Applied Sciences Wiener Neustadt, Austria

Former Positions:

- 2017 – 2018: Postdoctoral Researcher, Institute of Physics, University of Graz, Austria
- 2013 – 2017: Junior Scientist, Space Research Institute, Austrian Academy of Sciences, Graz, Austria
- 2011 – 2012: Assistant Researcher, Institute of Geophysics and Planetary Physics, Department of Earth and Space Sciences, University of California Los Angeles, USA
- 2007 – 2011: Research Associate and Doctoral Student, Institute for Geophysics and Extraterrestrial Physics, University of Braunschweig, Germany

Education:

- Doctorate in Natural Sciences (Dr. rer. nat.), University of Braunschweig, GERMANY (2011)
- Diploma in Physics (Dipl.-Phys.), University of Braunschweig, GERMANY (2007)

Services in National and/or International Committees:

- 2017 – 2018: Reviewer, NASA mission proposal review panel
- 2015 – 2018: Team-Leader, international team: “Jets downstream of collisionless shocks”, International Space Science Institute, Bern, Switzerland
- 2015: Reviewer, NASA heliophysics supporting research proposal review panel

Honors:

- 2016: NASA Group Achievement Award, MMS Instrument Suite Team
- 2012: Heinrich-Büssing-Award, University of Braunschweig
- 2011: Walter-Kertz-Studienpreis, University of Braunschweig
- 2005: Membership Studienstiftung des Deutschen Volkes

Mission involvements:

- Since 2018: Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) Magnetometer (MAG) Team Co-Investigator
- Since 2018: BepiColombo Mercury Planetary Orbiter (MPO) and Mercury Magnetospheric Orbiter (MMO) Magnetometer (MAG) Team Science Co-Investigator
- Since 2013: Magnetospheric Multiscale (MMS) Digital Flux-Gate (DFG) Magnetometer Team
- Since 2013: Jupiter Icy Moons Explorer (JUICE) Magnetometer (MAG) Team Science Co-Investigator
- Since 2008: Time History of Events and Macroscale Interactions during Substorms (THEMIS) Flux-Gate Magnetometer (FGM) Team

Selected Publications (from 89, first author of 19):

1. **Plaschke, F.**, H. Hietala, M. Archer, X. Blanco-Cano, P. Kajdic, T. Karlsson, S. H. Lee, N. Omidi, M. Palmroth, V. Roytershteyn, D. Schmid, V. Sergeev, and D. Sibeck (2018), Jets downstream of collisionless shocks, Space Sci. Rev., 214, 81, doi:10.1007/s11214-018-0516-3.

2. **Plaschke, F.**, H. Hietala, V. Angelopoulos, and R. Nakamura (2016), Geoeffective jets impacting the magnetopause are very common, J. Geophys. Res., 121, 3240-3253, doi:10.1002/2016JA022534.
3. **Plaschke, F.**, H. Hietala, and V. Angelopoulos (2013), Anti-sunward high-speed jets in the subsolar magnetosheath, Ann. Geophys., 31, 1877-1889, doi:10.5194/angeo-31-1877-2013.
4. **Plaschke, F.**, and K.-H. Glassmeier (2011), Properties of standing Kruskal-Schwarzschild-modes at the magnetopause, Ann. Geophys., 29, 1793-1807, doi:10.5194/angeo-29-1793-2011.
5. **Plaschke, F.**, K.-H. Glassmeier, H. U. Auster, O. D. Constantinescu, W. Magnes, V. Angelopoulos, D. G. Sibeck, and J. P. McFadden (2009), Standing Alfvén waves at the magnetopause, Geophys. Res. Lett., 36, L02104, doi:10.1029/2008GL036411.

ARCHER, Martin

Queen Mary University of London, UNITED KINGDOM

Role in the project: member, expertise on Earth foreshock and transients

Current position:

- Outreach Officer, School of Physics & Astronomy, QMUL, UK

Former Position(s):

- Visiting Researcher, Space & Atmospheric Physics, The Blackett Laboratory, Imperial College London, UK
- Research Associate, Space & Atmospheric Physics, The Blackett Laboratory, Imperial College London, UK

Education:

- PhD, Space Plasma Physics, Imperial College London, UK (2014)
- MSc, Physics with Theoretical Physics, Imperial College London, UK (2006)

Services in National and/or International Committees (last ones):

- European Geosciences Union Outreach Committee
- QMUL Centre for Public Engagement Grants Panel

Honors:

- QMUL Engagement & Enterprise Awards 2019, Public Engagement Involve Award
- QMUL Engagement & Enterprise Awards 2019, Best Opinion/Comment Piece
- SEPnet Public Engagement Awards 2017, Impact Project Award
- 2x NASA THEMIS Mission Research Highlights 2013
- Outstanding Student Paper Award, Space Physics & Aeronomy, AGU Fall Meeting 2012

Selected Publications (from 22 published):

1. **Archer, M.O.**, H. Hietala, M.D. Hartinger, F. Plaschke, V. Angelopoulos (2019) Direct observations of a surface eigenmode of the dayside magnetopause *Nature Commun.,* 10, 615 doi:10.1038/s41467-018-08134-5.
2. Palmroth, M., **M. Archer**, R. Vainio, H. Hietala, et al. (2015) ULF foreshock under radial IMF: THEMIS observations and global kinetic simulation Vlasiator results compared, *J. Geophys. Res. Space Physics*, 120, 8782–8798, doi:10.1002/2015JA021526.
3. **Archer, M.O**., D.L. Turner, J.P. Eastwood, S.J. Schwartz, T.S. Horbury (2015) Global impacts of a Foreshock Bubble: Magnetosheath, magnetopause and ground-based observations *Planet Space Sci.*, 106, 56-66 doi:10.1016/j.pss.2014.11.026
4. **Archer, M.**, T.S. Horbury, E.A. Lucek, C. Mazelle, A. Balogh, I. Dandouras (2005) Size and shape of ULF waves in the terrestrial foreshock, *J. Geophys. Res.*, 110, A05208, doi:10.1029/2004JA010791

BATTARBEE, Markus
Department of Physics, University of Helsinki, FINLAND

Role in the project: member, simulation expertise on shock and foreshock structures, particle acceleration, and particle injection at Earth and at the Sun

Current position:

- Postdoctoral researcher, Department of Physics, University of Helsinki, FINLAND

Former Positions:

- Postdoctoral research associate, Jeremiah Horrocks Institute, University of Central Lancashire, UK (2016 – 2017)
- Postdoctoral researcher, Department of Physics and Astronomy, University of Turku, FINLAND (2014 – 2015)

Education:

- PhD, Physics (space physics), University of Turku, FINLAND (2013)
- MSc, Physics, University of Turku, FINLAND (2008)

Honors:

- Invited expert, 1st international Vlasiator Science hackathon, Helsinki, FINLAND 2017
- Outstanding Student Paper Award, AGU Fall Meeting 2012

Selected Publications (from 35 published):

1. **M. Battarbee**, U. Ganse, Y. Pfau-Kempf, L. Turc, T. Brito, M. Grandin, T. Koskela, and M. Palmroth, Non-locality of the Earth's quasi-parallel bow shock: injection of thermal protons, *under revision at JGR: Space Physics*
2. Y. Pfau-Kempf, **M. Battarbee**, U. Ganse, S. Hoilijoki, L. Turc, S. von Alfthan, R. Vainio, and M. Palmroth (2018) On the importance of spatial and velocity resolution in the hybrid-Vlasov modeling of collisionless shocks**,** *Frontiers in Physics Vol. 6 p. 44* doi:10.3389/fphy.2018.00044
3. X. Blanco-Cano, **M. Battarbee**, L. Turc, A. P. Dimmock, E. K. J. Kilpua, S. Hoilijoki, U. Ganse, D. G. Sibeck, P. A. Cassak, R. C. Fear, R. Jarvinen, L. Juusola, Y. Pfau-Kempf, R. Vainio, and M. Palmroth (2018) Cavitons and spontaneous hot flow anomalies in a hybrid-Vlasov global magnetospheric simulation *Ann. Geophys., 36, 1081-1097* doi:10.5194/angeo-36-1081-2018
4. L. Turc, U. Ganse, Y. Pfau-Kempf, S. Hoilijoki, **M. Battarbee**, L. Juusola, R. Jarvinen, T. Brito, M. Grandin, and M. Palmroth (2018) Foreshock properties at typical and enhanced interplanetary magnetic field strengths: results from hybrid-Vlasov simulations *JGR: Space Physics 123* doi:10.1029/2018JA025466
5. **M. Battarbee**, R. Vainio, T. Laitinen and H. Hietala (2013) Injection of thermal and suprathermal seed particles into coronal shocks of varying obliquity *Astronomy & Astrophysics Vol. 558, A110* doi:10.1051/0004-6361/201321348
6. **M. Battarbee**, T. Laitinen and R. Vainio (2011) Heavy-ion acceleration and self-generated waves in coronal shocks *Astronomy & Astrophysics Vol. 535, A34* doi:10.1051/0004-6361/201117507

BERTUCCI, Cesar

Affiliation Instituto de Astronomía y Física del Espacio
(University of Buenos Aires / CONICET), ARGENTINA

Role in the project: member, expertise in the study of shock and upstream phenomena at Mars, Venus, comets, Titan and Saturn.

Current position:

- Principal Investigator at CONICET, ARGENTINA

Former Position(s):

- Independent Investigator at CONICET, ARGENTINA

Education:

- PhD, Planetology and Space Physics, Paul Sabatier University, Toulouse, France (2003)
- MSc, Astronomy, National University of Cordoba, Argentina (2000)

Services in National and/or International Committees (last ones):

- Member of the committee for investigator and project review at CONICET
- Member of evaluation panels and reviewer for the NASA Cassini Data Analysis Program.
- Reviewer of proposals for STFC (UK), Swedish Space Board, Hungarian Scientific Research Fund.

Honors:

- Houssay Award, Ministry of Science, Argentina (2015)
- NASA Team Achievement Award (2015, 2010)
- Argentine Academy of Sciences Award in Astronomy (2013)
- AGU Outstanding Student Award (2003).

Selected Publications:

1. **Bertucci, C.**; et al., Titan's interaction with the supersonic solar wind, Geophysical Research Letters, Volume 42, Issue 2, pp. 193-200, 2015 doi:10.1002/2014GL062106
2. **Bertucci, C.**, et al., Temporal Variability of Waves at the Proton Cyclotron Frequency Upstream from Mars: Implications for Mars Distant Hydrogen Exosphere, Geophys. Res. Lett., Volume 40, Issue 15, pp. 3809-3813, 2013 doi:10.1002/grl.50709
3. **Bertucci, C.**, et al., Low Frequency Waves in the Foreshock of Saturn: First Results From Cassini, J. Geophys. Res., Volume 112, Issue A9, CiteID A09219, 2007 doi:10.1029/2006JA012098
4. Andrés, N.; Meziane, K.; Mazelle, C.; **Bertucci, C.**; Gómez, D., The ULF wave foreshock boundary: Cluster observations, J. Geophys. Res.: Space Physics, Volume 120, Issue 6, pp. 4181-4193, 2015 doi:10.1002/2014JA020783
5. N. Andrés, D.O. Gómez, **C. Bertucci**, C. Mazelle, M.K. Dougherty, Saturn's ULF wave foreshock boundary: Cassini observations, Planet. Space Sci., Vol. 79, p. 64-75, 2013 doi:10.1016/j.pss.2013.01.014

BLANCO-CANO, Xóchitl
Instituto de Geofísica (IGEF), UNAM, México City, MEXICO

Role in the project: member, expertise in the study of shock and upstream phenomena at Earth, interplanetary shocks and Mercury. In-situ data and comparison with simulations

Current position:

- Full Professor (Investigador Titular C), Academic Secretary IGEF (October 2017 –)

Education:

- PhD, Astrophysics, Queen Mary and Westfield College, University of London, UK (1995) "Waves and particles upstream of the Earth's Bow Shock"

Services in National and/or International Committees (last ones):

- Referee: Journal of Geophysical Research, Planetary and Space Science, Geophysical Research Letters, Solar Physics, Astrophysical J., Atmosphere and Solar Physics, Annales Geophysicae. Guest Editor: Advances in Space Res. 2004-2005; Solar Physics, 2016 – 2017.
- Reviewer of: Proposals funded by CONACYT, 2008-present. NSF, EUA, 2008; DGAPA, PAPIIT, UNAM 2011-2013; NASA, EUA, 2012 –
- Member of the Comittee Awards of the Mexican Academy of Sciences, 2014 – 2017.

Appointments:

- CLUSTER (ESA) Mission Guest Investigator, "Upstream transients and their influence on the bow shock and magnetosheath", 2015 – 2016.

Selected Publications:

1. **Blanco-Cano, X**., N. Omidi and C. T. Russell, Macrostructure of collisionless bow shocks: 2. ULF waves in the foreshock and magnetosheath, *J. Geophys. Res.*, 111, A10, 2006 doi:10.1029/2005JA011421
2. **Blanco-Cano, X**.; Omidi, N.; Russell, C. T., Global hybrid simulations: Foreshock waves and cavitons under radial IP magnetic field geometry, *J. Geophys. Res.*,114, 2009 doi:10.1029/2008JA013406
3. **Blanco-Cano X**., Kajdič P., Omidi N., Russell C. T., Foreshock cavitons for different interplanetary magnetic field geometries: simulations and observations, Journal of Geophysical Research, 116 (A9), 2011 doi:10.1029/2010JA016413
4. Le G., Chi P. J., **Blanco-Cano X**., Boardsen et al., Upstream ultra-low frequency waves in Mercury's foreshock region: MESSENGER magnetic field observations, J. Geophys. Res., Volume 118, Issue 6, pp. 2809-2823, 2013 doi:10.1002/jgra.50342
5. Kajdič, P**.**, **Blanco-Cano, X**., Omidi, N., Meziane, K., Russell, C. T.: Statistical study of foreshock cavitons, Annales Geophysicae, 31, 2163-2178, 2013 doi:10.5194/angeo-31-2163-2013
6. Kajdič, P., B. Lavraud, A. Zaslavsky, **X. Blanco-Cano**, J.-A. et al.,Ninety degrees pitch angle enhancements of suprathermal electrons associated with IP shocks, *J. Geophys. Res.*, 2014 doi:10.1002/2014JA020213
7. **Blanco-Cano X**., P. Kajdič, E. Aguilar-Rodríguez et al., Interplanetary shocks and foreshocks observed by STEREO during 2007-2010, J. Geophys. Res.,121, Issue 2, pp. 992-1008, 2016, 2016 doi:10.1002/2015JA021645
8. **Blanco-Cano, X.,** Battarbee, M., Turc, L., Dimmock, A. P., Kilpua et al., Cavitons and spontaneous hot flow anomalies in a hybrid-Vlasov global magnetospheric simulation, Ann. Geophys., 36, 1081-1097, 2018 doi:10.5194/angeo-36-1081-2018

COLLINSON, Glyn

NASA Goddard Space Flight Center, USA

Role in the project: member, expertise on the foreshocks of Venus and Mars, observation-simulation comparisons

Current position:

- University Scientist (contractor), NASA Goddard Space Flight Center, Heliophysics Science Division, USA

Former position(s):

- NASA Postdoctoral Fellow, NASA Goddard Space Flight Center, Greenbelt, MD, USA

Education:

- PhD, Space Science, University College London, UK (2010)
- MSc, Physics with Industrial Experience, University of Bristol, UK (2005)

Selected publications:

1. **Collinson, G.A.**, et al., "*Solar Wind induced waves in the skies of Mars: Ionospheric compression, energization, and escape resulting from the impact of ultra-low frequency magnetosonic waves generated upstream of the Martian bow shock*", J. Geophys. Res. Space Phys., vol. 123, (2018) doi:10.1029/2018JA025414
2. **Collinson, G.A.**, et al. "*Spontaneous Hot Flow Anomalies at Mars and Venus*", J. Geophys. Res. Space Physics, 122, pp. 9910-9923, (2017) doi:10.1002/2017JA024196
3. Omidi, N. et al. (including **G. Collinson**), "*Structure and Properties of the Foreshock at Venus*", J. Geophys. Res. Space Physics, 122, pp. 10275-10286, (2017) doi:10.1002/2017JA024180
4. **Collinson, G.A.**, et al. "A Hot Flow Anomaly at Mars", Geophys. Res. Lett., 42, pp.9127-9127, (2015) doi:10.1002/2015GL065079
5. **Collinson, G.A.**, et al. "*A Survey of Hot Flow Anomalies at Venus*", Journal of Geophysical Research – Space Physics, 119, Issue 2, pp. 978–991, (2014) doi:10.1002/2013JA018863
6. **Collinson, G.A.**, et al. "*Short Large Amplitude Magnetic Structures (SLAMS) at Venus*", J. Geophys. Res. Space Physics, 117, A10221, (2013c) doi:10.1029/2012JA017838
7. **Collinson, G.A.**, et al., *"Hot Flow Anomalies at Venus"*, Journal of Geophysical Research (Space Physics), vol. 117, A04204, (2012b) doi:10.1029/2011JA017277

KARLSSON, Tomas

Space and Plasma Physics, KTH Royal Institute of Technology,
Stockholm, SWEDEN

Role in the project: member, expertise on Earth bow shock and magnetosheath, Mercury magnetospheric system, cometary environment

Current position:

- Associate Professor, KTH Royal Institute of Technology, Stockholm, SWEDEN

Education:

- PhD, Royal Institute of Technology, Stockholm, SWEDEN (2002)
- BSc, Institute for Theoretical Physics, Lund University, SWEDEN (1991)

Mission involvements and honors:

- Co-I on the Solar Orbiter mission.
- Co-I on the Rosetta LAP instrument.
- Lead Co-I for the MEFISTO instrument on BepiColombo/MMO.

Selected Publications (from >100):

1. **Karlsson, T.**, Plaschke, F., Hietala, H., Archer, M., Blanco-Cano, X., Kajdič, P., Lindqvist, P.-A., Marklund, G., and Gershman, D. J., Investigating the anatomy of magnetosheath jets – MMS observations, Ann. Geophys., 36, 655-677, doi:10.5194/angeo-36-655-2018, 2018.
2. **Karlsson, T.**, A. I. Eriksson, E. Odelstad, M. André , G. Dickeli, K.-H. Glassmeier,A. Kullen, P.-A Lindqvist, H. Nilsson, and I. Richter, Rosetta measurements of lower hybrid frequency range electric field oscillations in the plasma environment of comet 67P, Geophys. Res. Lett., 44, doi:10.1002/2016GL072419, 2017.
3. Liljeblad, E. and **Karlsson, T.**, Investigation of ~ 20–40 mHz ULF waves and their driving mechanisms in Mercury's dayside magnetosphere, Ann. Geophys., 35, 879-884, doi:10.5194/angeo-35-879-2017, 2017.
4. **Karlsson, T.**, E. Liljeblad, A. Kullen, J. M. Raines, J. A. Slavin, T. Sundberg, Isolated magnetic field structures in Mercury's magnetosheath as possible analogues for terrestrial magnetosheath plasmoids and jets, Planetary and Space Science, Volume 129, 61-73, (2016) doi:10.1016/j.pss.2016.06.002.
5. **Karlsson, T.**, A. Kullen, E. Liljeblad, N. Brenning, H. Nilsson, M. Hamrin, On the origin of magnetosheath plasmoids, and their relation to magnetosheath jets, J. Geophys. Res., 120, (2015) doi:10.1002/2015JA021487.
6. **Karlsson, T.**, N. Brenning, H. Nilsson, J.-G. Trotignon, X. Vallières, and G. Facsko, Localized density enhancements in the magnetosheath: Three dimensional morphology and possible importance for impulsive penetration, J. Geophys. Res., 117, A03227, (2012) doi:10.1029/2011JA017059.

LONG, David

Mullard Space Science Laboratory, University College London, UK

Role in the project: member, expertise in the solar corona, shocks and high-energy particles, remote-sensing.

Current position:

- Lecturer in Solar Physics

Former Position(s):

- University of Dublin, Trinity College, 2003 – 2011
- Harvard-Smithsonian Centre for Astrophysics, 2010 – 2011
- MSSL-UCL, 2011 – current

Education:

- PhD, Solar Astrophysics, University of Dublin, Trinity College, IRELAND (2011)
- B.A. Mod., Physics with Astrophysics, University of Dublin, Trinity College, IRELAND (2007)

Services in National and/or International Committees (last ones):

- Active reviewer for proposals submitted for funding to NASA, including Postdoctoral Program (NPP) and Heliophysics Supporting Research (HSR).
- Elected member of UK Solar Physics Council

Honors:

- Solar Orbiter/EUI Co-Investigator
- Solar-C Co-Investigator
- COSIE Co-Investigator
- Co-Leader in the proposal "The Nature of Coronal Bright Fronts" selected for funding by the International Space Science Institute (ISSI, 2013).

Selected Publications (from 30, >656 citations):

1. **Long, D. M.**, Bloomfield, D. S., Chen, P.-F., Downs, C., *et al.*, (2017), Understanding the physical nature of "EIT waves", Solar Physics, 292, 7. Doi:10.1007/s11207-016-1030-y
2. **Long, D. M.**, Baker, D., Williams, D. R., Carley, E. P., Gallagher, P. T., Zucca, P., (2015), The energetics of a global shock wave in the low solar corona, Ap.J, 799, 2 doi:10.1088/0004-637X/799/2/224
3. Prise, A. J., Harra, L. K., Matthews, S. A., **Long, D. M.**, Aylward, A.~D., (2014), An investigation into the CME of 3 November 2011 and its associated widespread solar energetic particle event, Solar Physics, 289, 5 doi:10.1007/s11207-013-0435-0
4. Carley, E. P., **Long, D. M.**, Byrne, J. P., Zucca, P., *et al.,* (2013), Quasi-periodic acceleration of electrons by a plasmoid-driven shock in the solar atmosphere, Nature Physics, **9**, 811 doi:10.1038/nphys2767
5. Ma, S., Raymond, J. C., Golub, L., Lin, J., Chen, H., Grigis, P., Testa, P., **Long, D. M.**, (2011), Observations and Interpretation of a low coronal shock wave observed in the EUV by the SDO/AIA, ApJ, 736, 2 doi:10.1088/0004-637X/738/2/160

OPHER, Merav

Boston University, USA

Role in the project: member, expertise on the heliosheath/termination shock, global and localized multi-fluid MHD simulations

Current position:

- Associate Professor, Department of Astronomy, Boston University, USA

Education:

- PhD, Physics & Astronomy, University of Sao Paulo, BRAZIL (1998)
- BSc, Physics, University of Sao Paulo, BRAZIL (1992)

Services in National and/or International Committees (last ones):

- Editor, Geophysical Research Letters (2017-2020)
- Member, NRC Committee to Assess the 2012 Solar and Space Physics Decadal Survey (2019)
- Chair-Elect, American Physical Society (APS) Topical Group in Plasma Astrophysics (2017 – 2018)
- Member, NASA Heliophysics Mission Senior Review Panel, 2015, 2017
- Member, Decadal Survey in Space Physics of Solar and Heliospheric Panel (2010 – 2011) – *chaired the Outer Heliosphere sub-panel*
- Member, Decadal Survey in Space Physics of the Theory and Modeling Group (2010 –)

Honors:

- PECASE - Presidential Early Career Award for Scientists and Engineers (2008)
- NSF Young Investigator CAREER award (2008)
- Kavli Fellow, National Academy of Science (2008)

Selected Publications:

1. **Opher, M.**, Drake, J. F., Swisdak, M., Zieger, B. ♦, Toth, G., “The Twist of the Draped Interstellar Magnetic Field Ahead of the Heliopause: A Magnetic Reconnection Driven Rotational Discontinuity”, *The Astrophysical Journal Letters,* Vol. 839, L12 (2017) doi:10.3847/2041-8213/aa692f
2. **Opher, M.**, Drake, J. F., Zieger, B., Gombosi, T. I. “Magnetized Jets Driven by the Sun: The Structure of the Heliosphere Revisited”, *The Astrophysical Journal Letters,* Vol. 800, L28 (2015) doi:10.1088/2041-8205/800/2/L28
3. **Opher**, **M.,** F. Alouani Bibi, G. Toth, J. D. Richardson, V. V. Izmodenov, and Gombosi, T. I., “A Strong highly-tilted Interstellar Magnetic Field near the Solar System”, *Nature*, Vol. 462, 1036 (2009) doi:10.1038/nature08567

SERGIS, Nick

Academy of Athens, Office of Space Research and Technology, Athens, GREECE

Role in the project: member, expertise on Saturn and high-energy particles.
Current position:

- Researcher, Academy of Athens and National Observatory of Athens.

Former Position(s):

- University of Athens

Education:

- PhD, Space Physics, University of Athens, GREECE (2006)
- MSc, Astronomy and Astrophysics, University of Athens, GREECE

Services in National and/or International Committees (last ones):

- Active reviewer for proposals submitted for funding to NASA, through the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES).
- European Commission expert (assignments that include the evaluation of proposals, monitoring of projects, and evaluation of programs).
- Member of the "Neptune and Triton Working Group" mission to Neptune and Triton proposed to the ESA, under the 2nd and 3rd Large Missions Call of the ESA Cosmic Vision Program 2015 – 2025.

Honors:

- NASA Group Achievement Award for exceptional operation and data analysis during the Cassini mission (2019).
- Member of the Editorial Board of The Annales Geophysicae (2017).
- Co-Leader in the proposal "Modes of radial plasma motion in planetary systems" selected for funding by the International Space Science Institute (ISSI, 2014).
- NASA Group Achievement Award for participation to the Cassini Magnetospheric Imaging Instrument (2009).
- Best Reviewer in the field of Magnetosphere and Space Plasma Physics, Annales Geophysicae, elected by the editorial board (2009).

Selected Publications (from 71):

1. **Sergis N.**, C.M. Jackman, A. Masters, S.M. Krimigis, M.F. Thomsen, D.C. Hamilton, D.G. Mitchell, M.K. Dougherty, A.J. Coates, (2013), Particle and magnetic field properties of the Saturnian magnetosheath: Presence and upstream escape of hot magnetospheric plasma, JGR Space Physics, Vol. 118, pp. 1620–1634. doi:10.1002/jgra.50164
2. Masters A., Sulaiman A., **Sergis N.**, Stawarz L., Fujimoto M., Coates A.J., Dougherty M.K., (2016), Suprathermal Electrons at Saturn's Bow Shock, Ap.J, Vol. 826, Iss. 1. doi:10.3847/0004-637X/826/1/48
3. Bertucci, C., D. Hamilton, W. Kurth, G. Hospodarsky, D. Mitchell, **N. Sergis**, N. Edberg, M. Dougherty (2015), Titan's interaction with the supersonic solar wind, GRL, 42. doi:10.1002/2014GL062106
4. Masters A., Stawarz L., Fujimoto M., Schwartz S.J., **Sergis N.**, Thomsen M.F., Retinò A., Hasegawa H., Zieger B., Lewis G.R., Coates A.J., Canu P., Dougherty M.K., (2013), Electron acceleration to relativistic energies at a strong quasi-parallel shock wave, Nature Physics, Vol. 9, Issue 3, pp. 164-167. doi:10.1038/nphys2541

LIU, Terry Z. (Zixu Liu)

University of California, Los Angeles, USA

Role in the project: early-career scientist, expertise on in-situ observations of Earth's foreshock transients, magnetosheath jets, and associated particle acceleration

Current position:

- Assistant researcher, Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, USA

Education:

- PhD, Geophysics and Space Physics, University of California, Los Angeles, USA (2018)
- BSc, Space Science and Technology, Peking University, CHINA (2013)

Honors:

- Harold and Mayla Sullwold Scholarship at EPSS, UCLA in 2017
- Outstanding Poster Award at GEM conference in 2017
- Outstanding Student Paper Award at AGU Fall Meeting in 2016
- Eugene B. Waggoner Scholarship at EPSS, UCLA in 2016
- Outstanding Poster Award at GEM conference in 2016

Selected Publications:

1. Turner D. L., L. B. Wilson III, **T. Z. Liu**, et al. (2018), Autogenous and efficient acceleration of energetic ions upstream of Earth's bow shock. Nature, 561, 206, doi:10.1038/s41586-018-0472-9
2. **Liu, T. Z.**, V. Angelopoulos, H. Hietala, and L. B. Wilson III (2017), Statistical study of particle acceleration in the core of foreshock transients, J. Geophys. Res. Space Physics, 122, doi:10.1002/2017JA024043. **Editor's Highlight**
3. **Liu, T. Z.**, H. Hietala, V. Angelopoulos, and D. L. Turner (2016), Observations of a new foreshock region upstream of a foreshock bubble's shock, Geophys. Res. Lett., 43, doi:10.1002/2016GL068984. **Geophys. Res. Lett. Cover Image**
4. **Liu, Z.**, D. L. Turner, V. Angelopoulos, and N. Omidi (2015), THEMIS observations of tangential discontinuity-driven foreshock bubbles, Geophys. Res. Lett., 42, doi:10.1002/2015GL065842.