Exploring astrophysically relevant bow shocks using MIFEDS and the OMEGA laser

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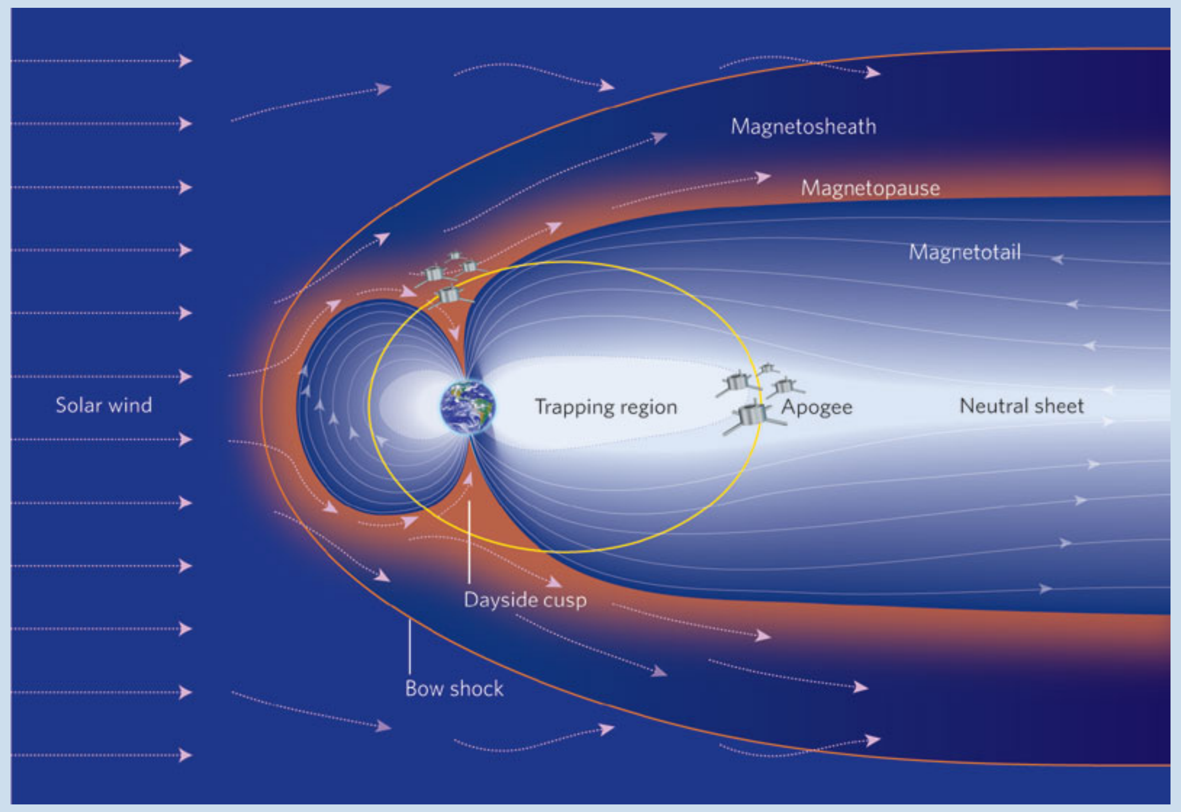
Introduction

Magnetized astrophysical bow shocks form when incoming supersonic plasma flow encounters a strong enough magnetic field. The shock occurs when the magnetic pressure is equal to the incoming ram pressure,

$$\frac{B_0^2}{2\mu_0} = \rho v^2.$$

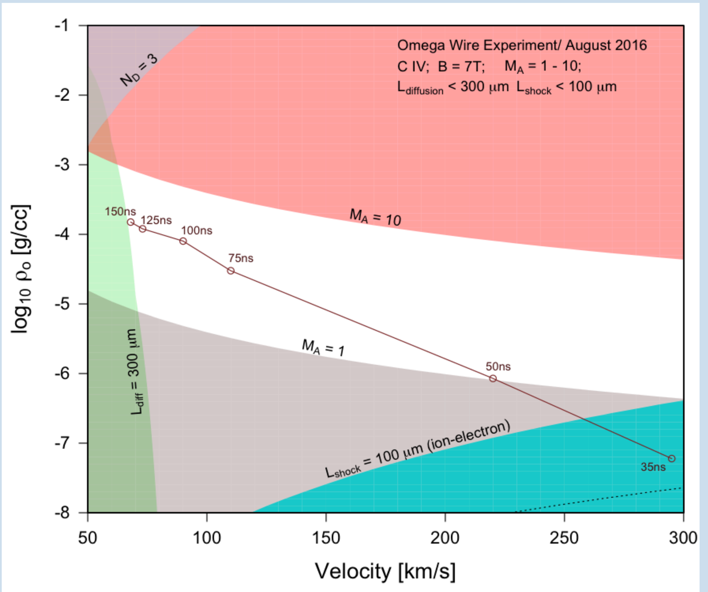
The most well-studied example of such a system is the Earth-Sun magnetosphere system, in which the incoming solar wind interacts with the Earth's magnetosphere.



M. L. Goldstein, Nature 2005, doi: 10.1038/436782a

Forming a magnetized bow shock

The goal of our experiments is to observe how a magnetic field changes the bow shock structure in time. Observing dynamical effects requires a specific regime of plasma flow and magnetic field, and we are limited by the experimental platform.



- White region: parameters needed for magnetized shock formation
- Red line: simulated evolution of flow with time

Image by Dr. Pat Hartigan

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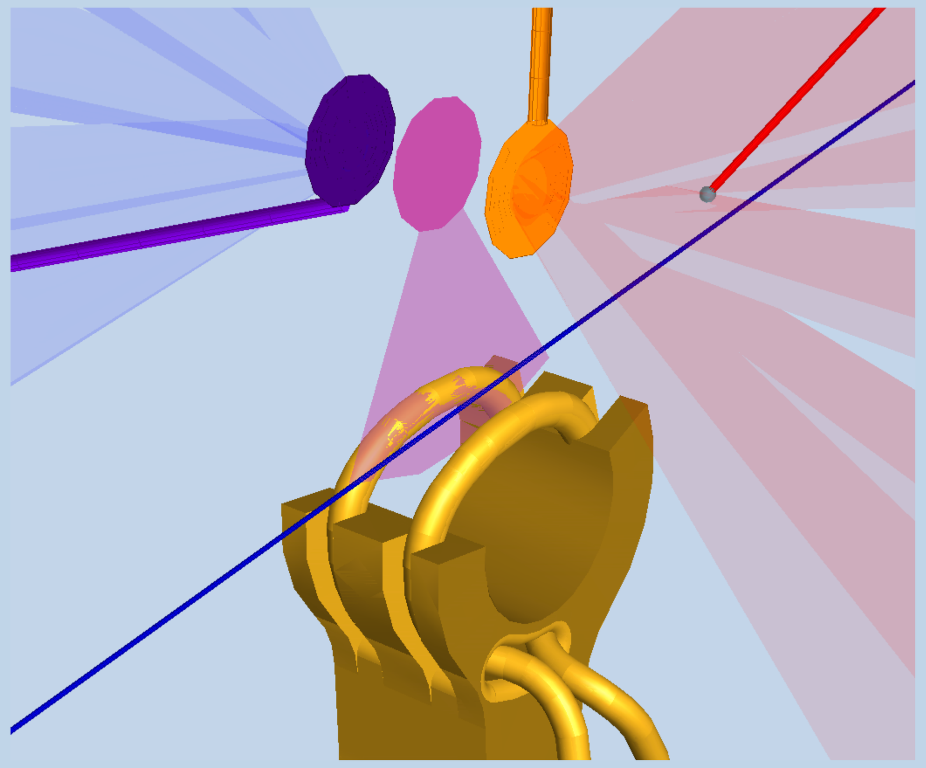
Experiment details

Primary diagnostics:

- TPDI (Two-Plasmon Decay Imager): optical imager to view plasma emission
- Proton radiography: uses protons to probe magnetic fields, CR39 used as detector to track damage from incident protons

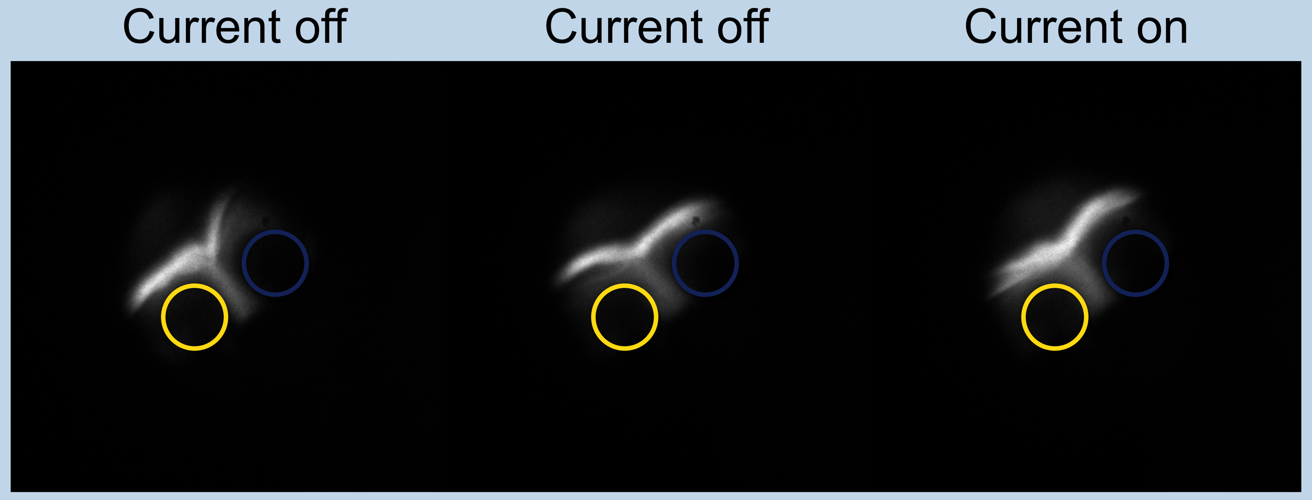
Experimental design:

- Two carbon foils rear-irradiated with 6, 1 ns laser beams each
- Counter-propagating plasma flow from foils collides at center plane (pink) and expands laterally toward the wire targets (gold) at lower density / velocity
- Flow interacts with wires / MIFEDS, forming a shock
- Laser-driven D[3]He implosion (blue sphere) produces protons at 3 and 14.7 MeV
- Protons probe region of magnetic field, impact 9.6 x 9.6 cm CR39 detector



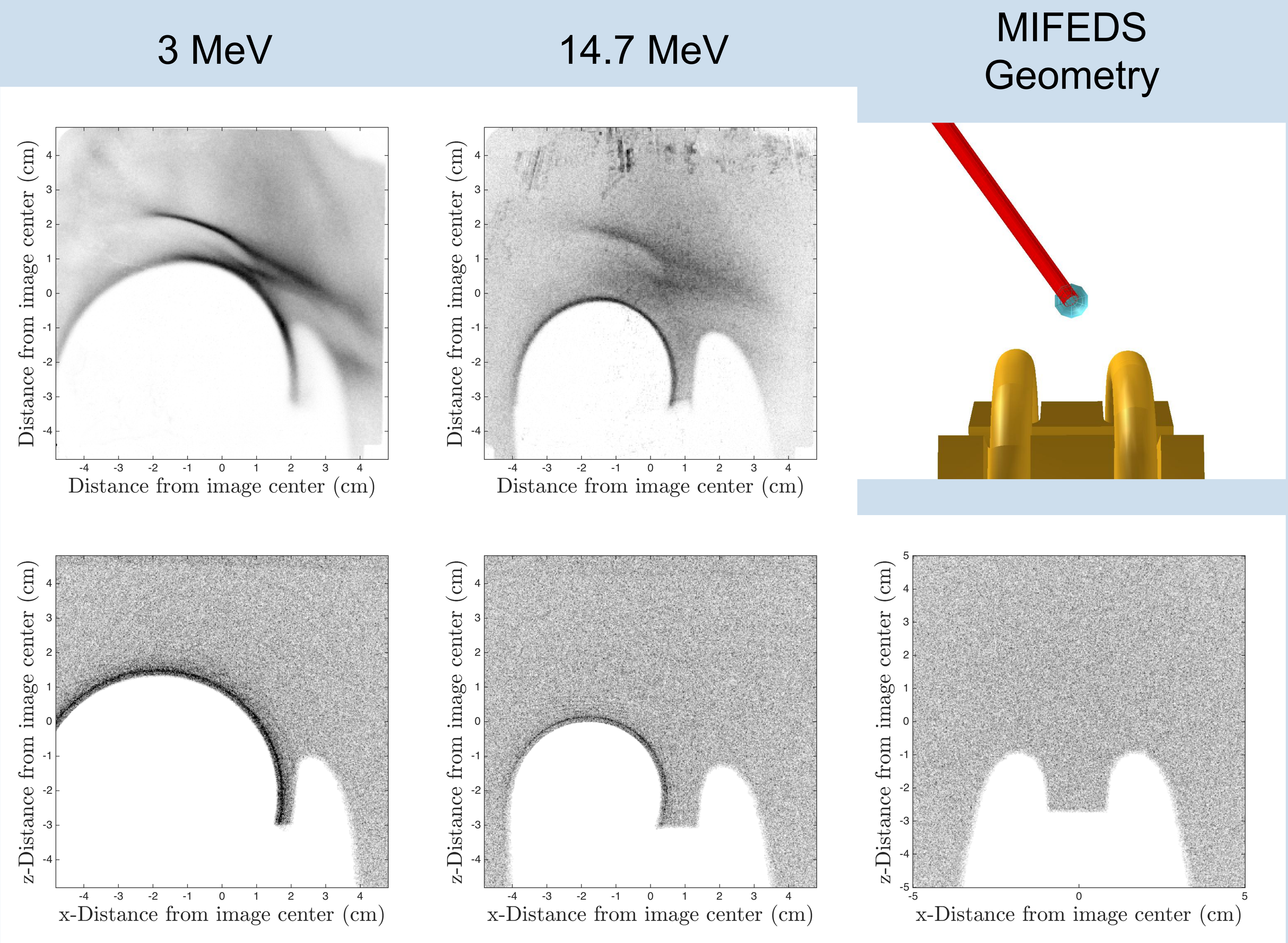
- Additionally, some shots were run without proton backlighting to use TPDI to capture optical emission from flow / shock

TPDI shows that the flow direction can vary greatly between shots



- Shock structure apparent in all images
- Above shots taken at same drive time (60 ns)
- Variation in flow direction much greater than due to magnetic fields
- Having two wires likely makes problem worse

Proton radiography simulations show good agreement with data



- Comparison of processed CR39 images and MIFEDS geometry (top) with simulations using the measured wire current from the corresponding shot (bottom)
- The large void ring in the center and left images is caused by deflection of protons away from the wire from its magnetic field
- The additional structures in the data are likely due to the shock from the incoming plasma flow
- Difficult to disentangle shock structure from images due to 3D flow variations (into and out of page)

Conclusions

- Our two-foil plasma drive produces the required conditions for the production of a bow shock
- Plasma flow direction shows large shot-to-shot variation
- Proton radiography is the preferred diagnostic, and simulations can be used to confirm or predict image structure

Future work

- Change to single wire to reduce effect of flow direction variation and see the shock drape around the structure
- Use proton radiography with this system for different wire currents to determine effect of B field
- Characterize the incoming flow and ablation flow parameters across the shock using Thomson scattering

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