

Shock waves in space

Shock waves

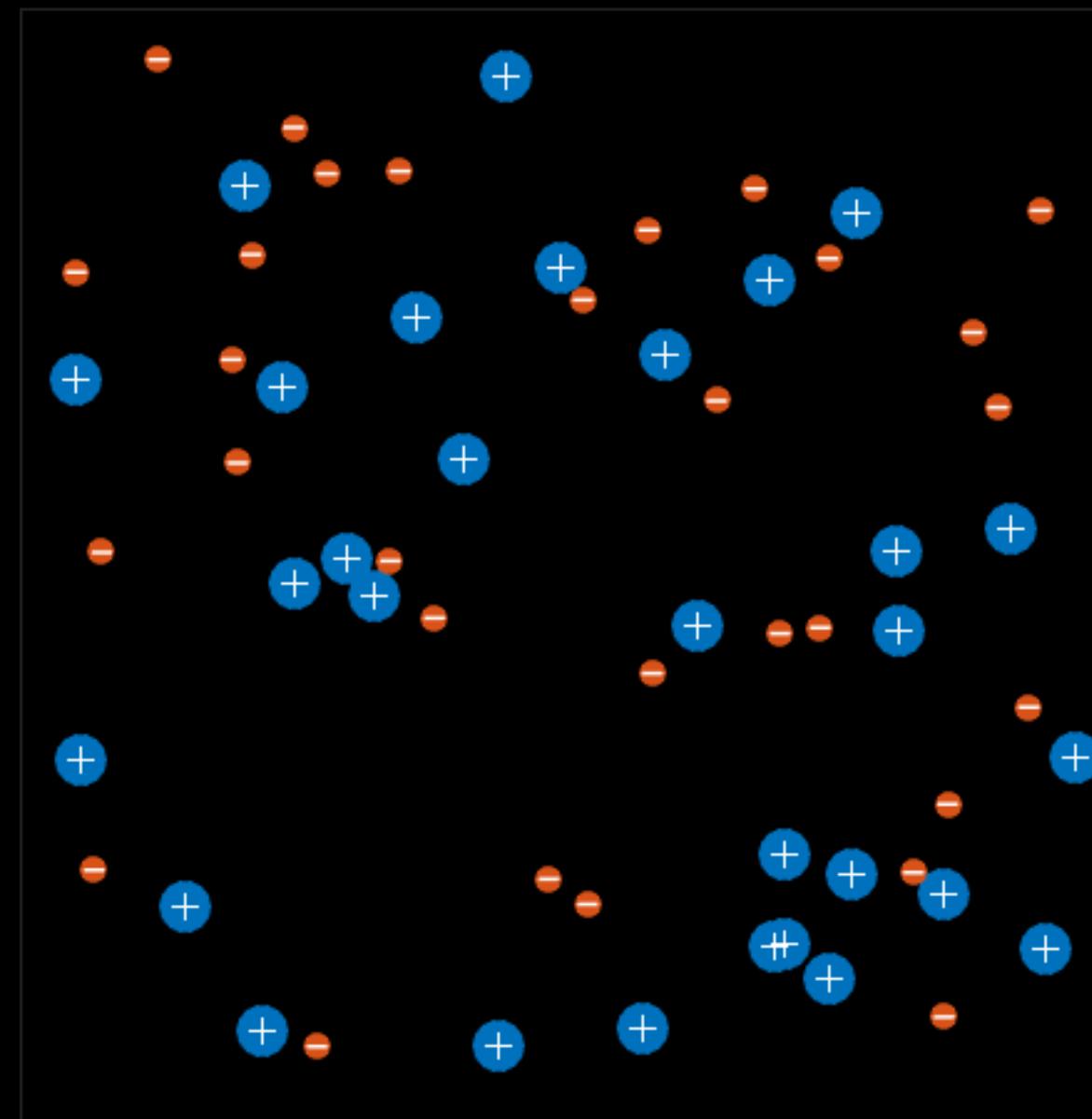
Appear when a gas flowing faster than the speed of sound encounters an obstacle



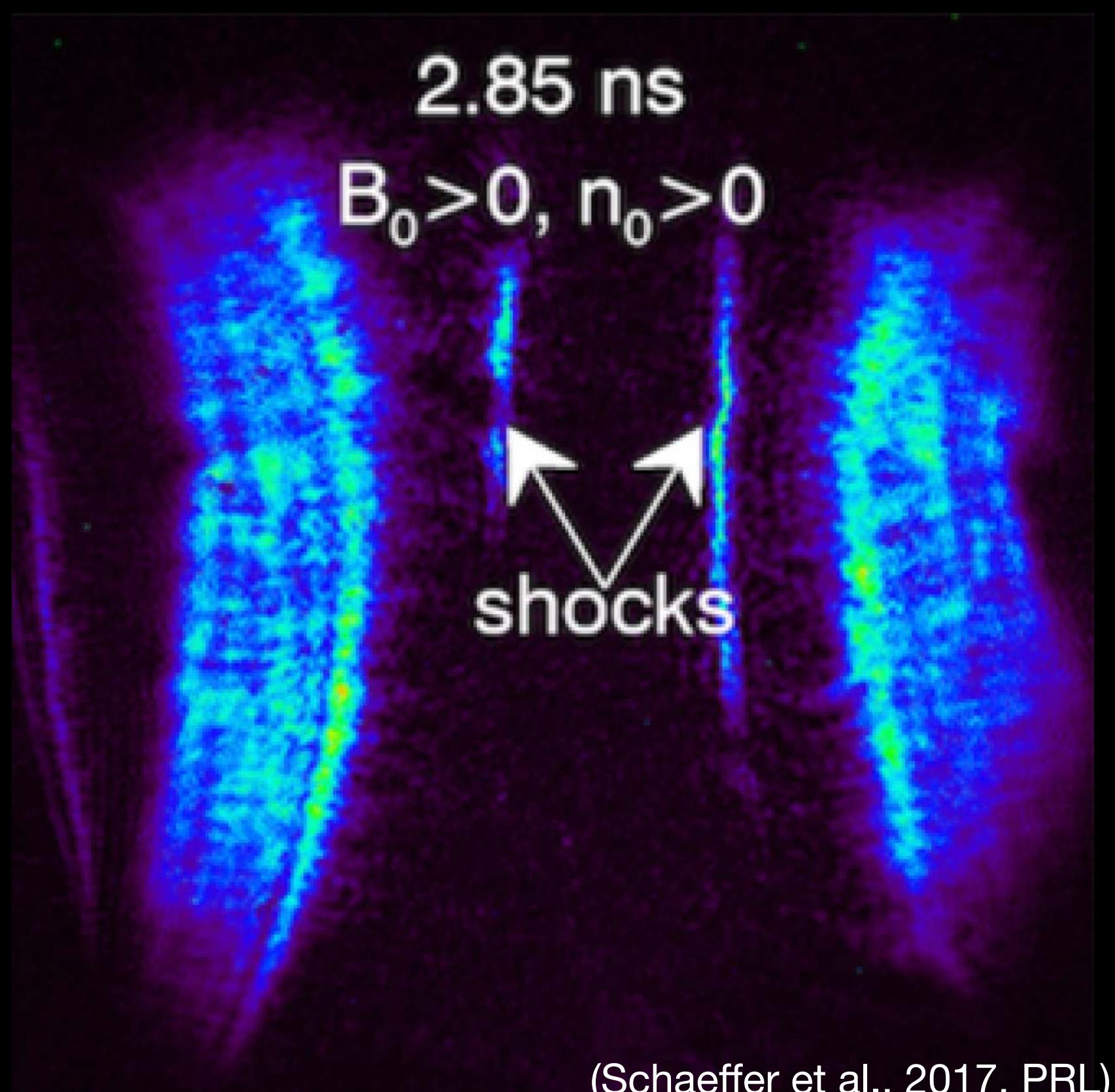
<https://www.youtube.com/smartereveryday>

Plasma shock waves

- Plasma is the fourth state of matter and consists of free charged particles
- In a collisionless plasma, particles only interact with each other through electromagnetic fields

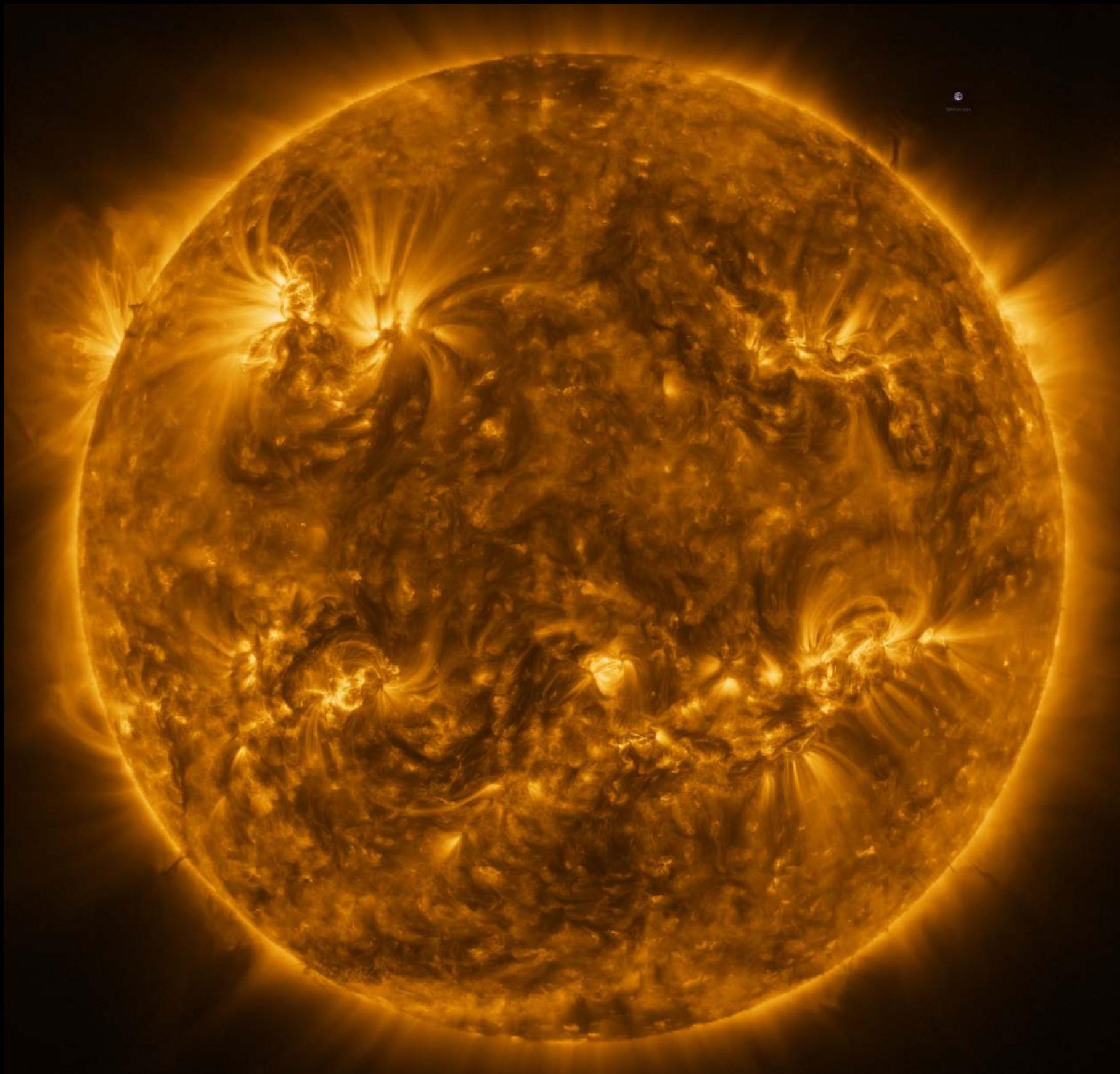


Two shock waves in a collisionless plasma obtained by shooting lasers at two opposing plastic plates



(Schaeffer et al., 2017, PRL)

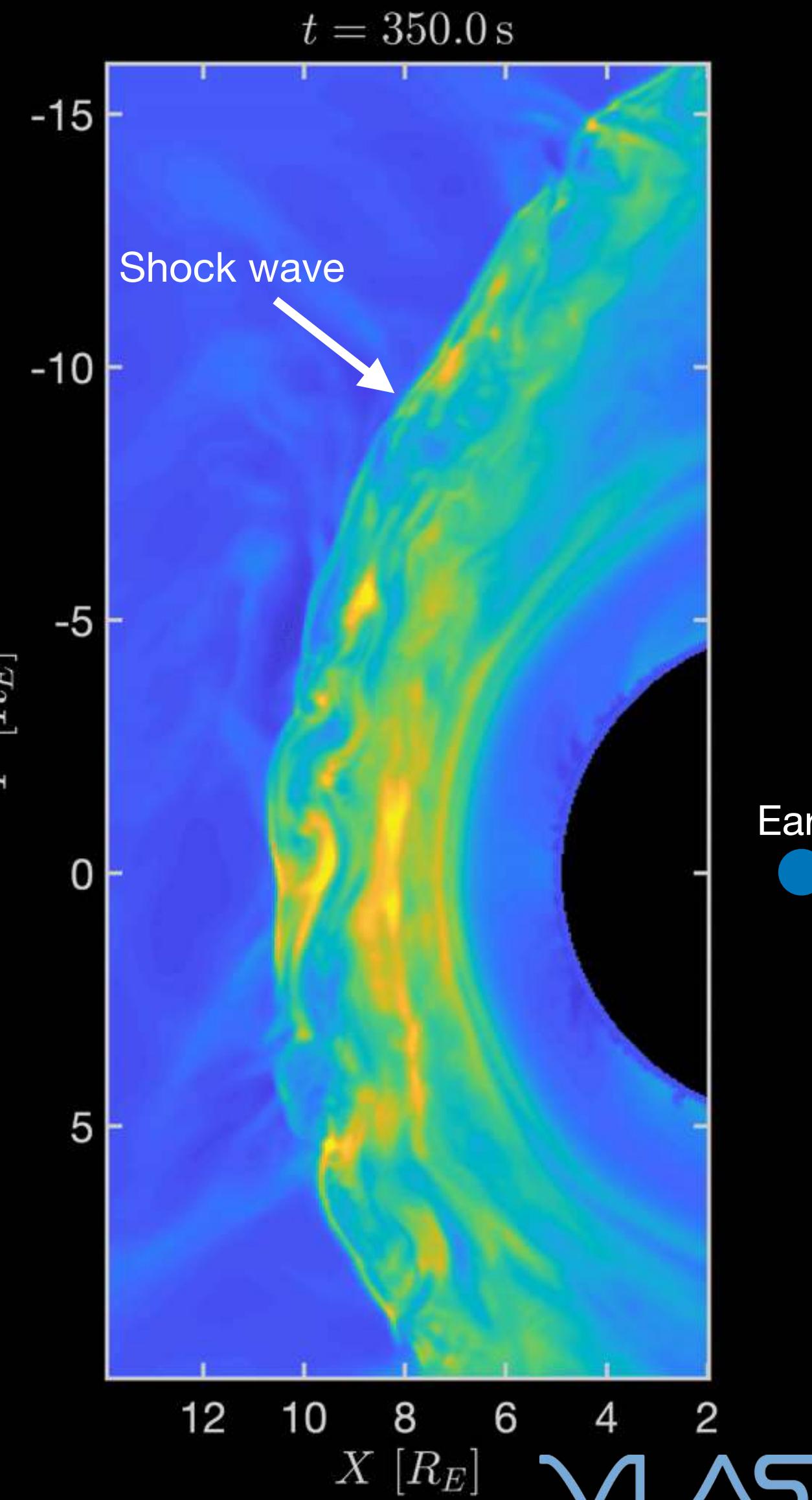
Shock waves in space



A bow shock forms in front of Earth when the **solar wind** encounters the planet's magnetic field

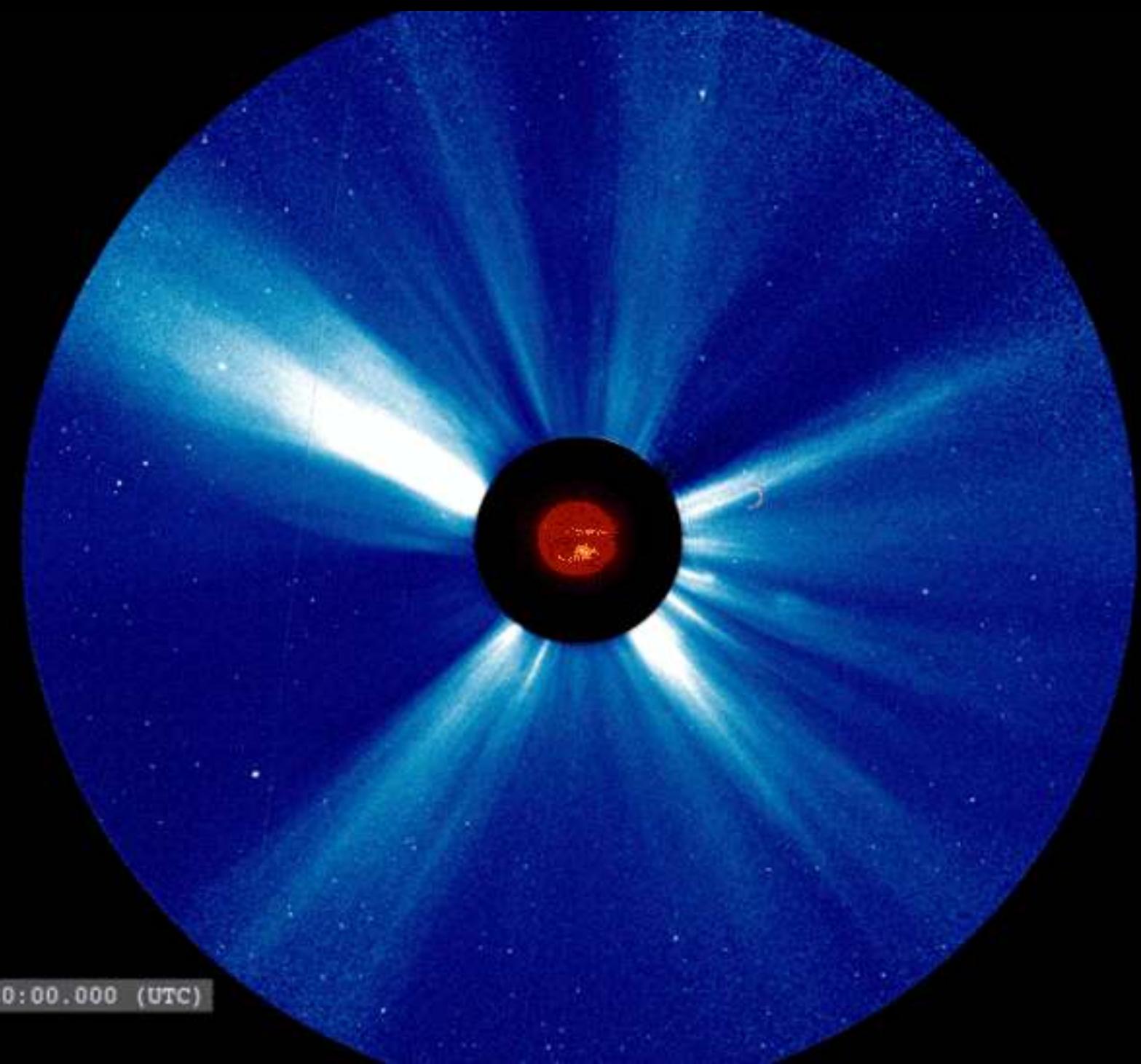


Simulation of Earth's bow shock showing plasma density



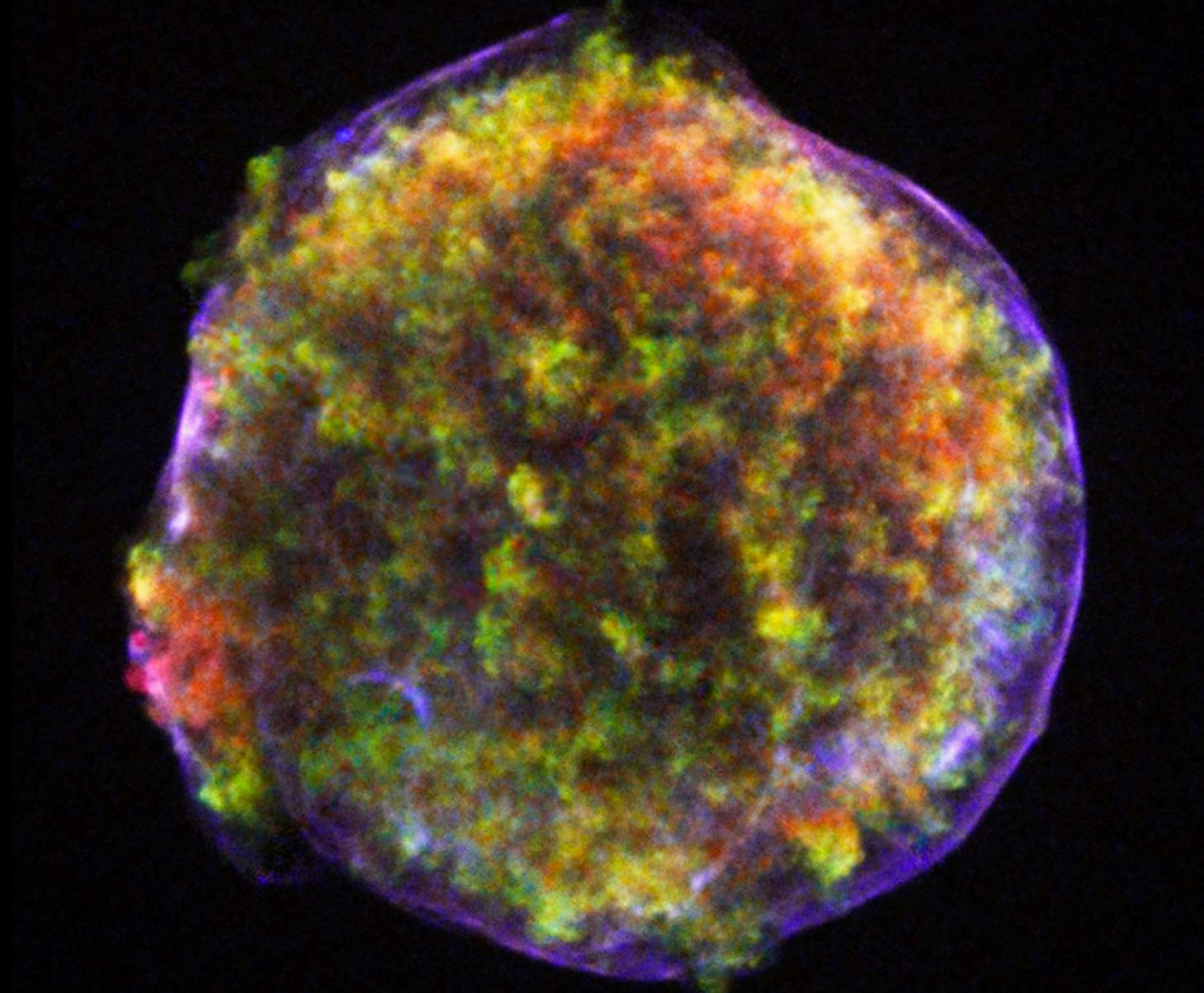
Particle acceleration

Shock waves from solar eruptions accelerate solar energetic particles which pose a threat to astronauts and satellites



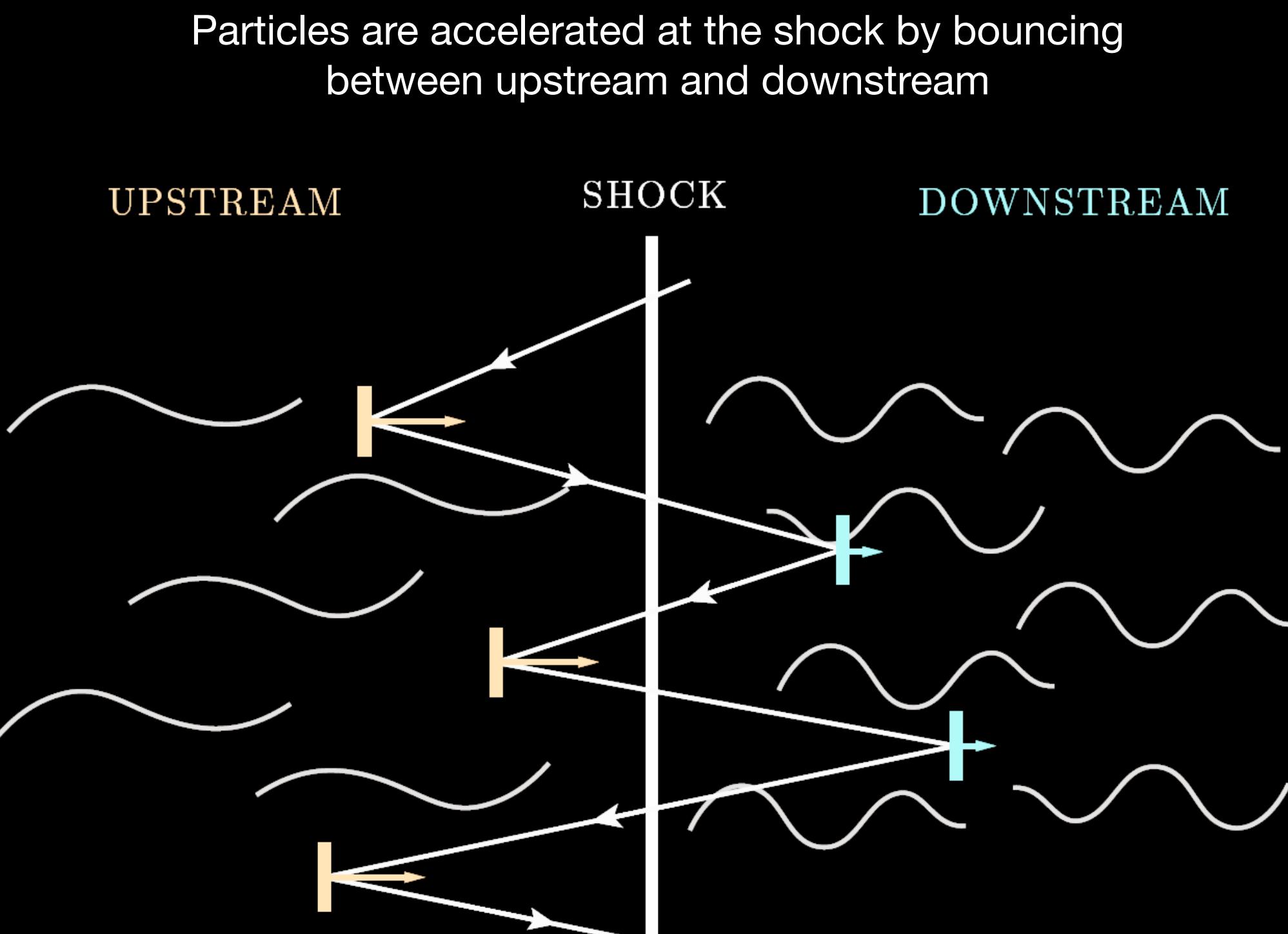
NASA/STEREO

Collisionless shocks in supernova remnants accelerate the extremely energetic galactic cosmic rays that we observe on Earth



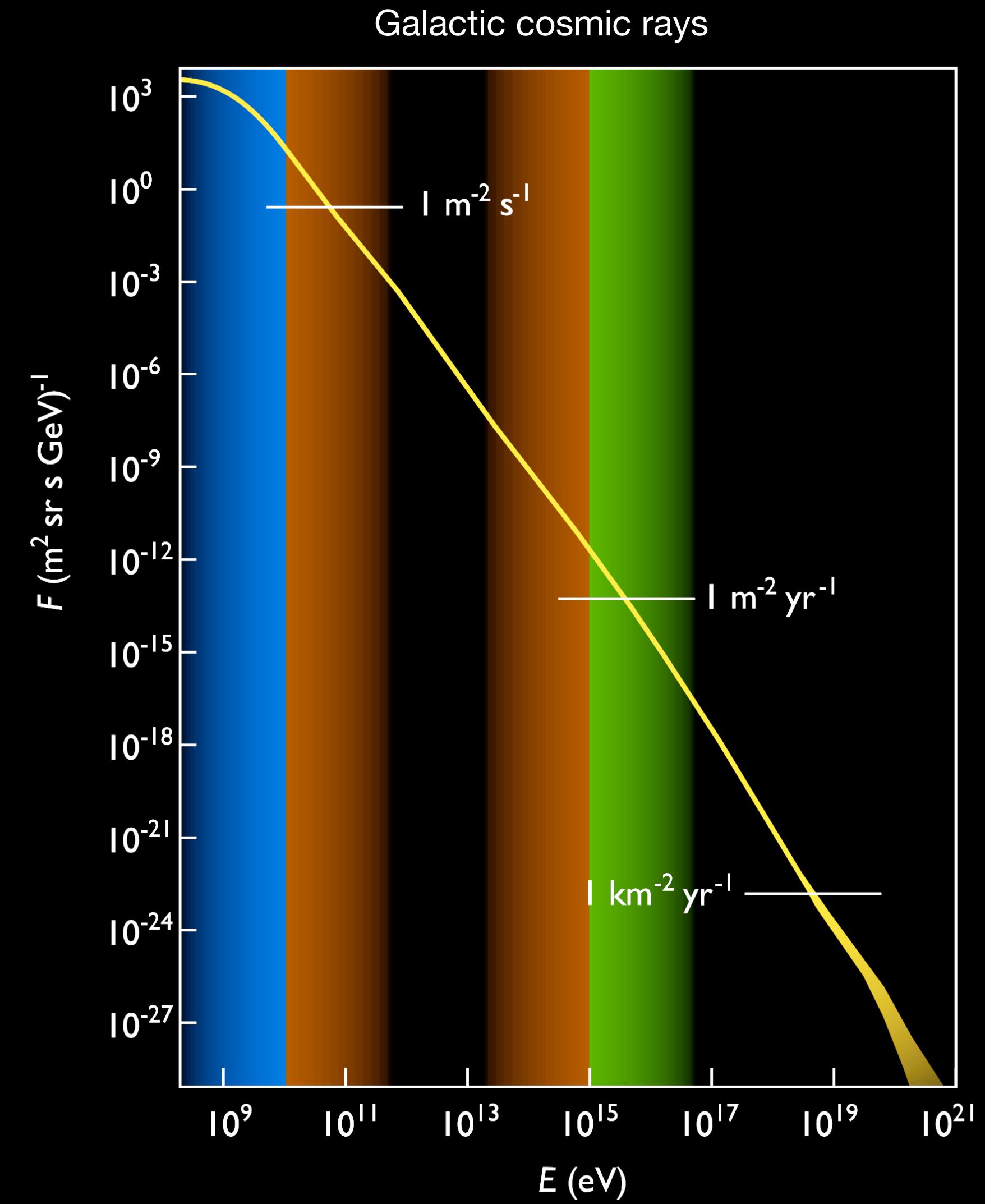
Tycho's supernova remnant in X-rays - NASA/CXC

Particle acceleration



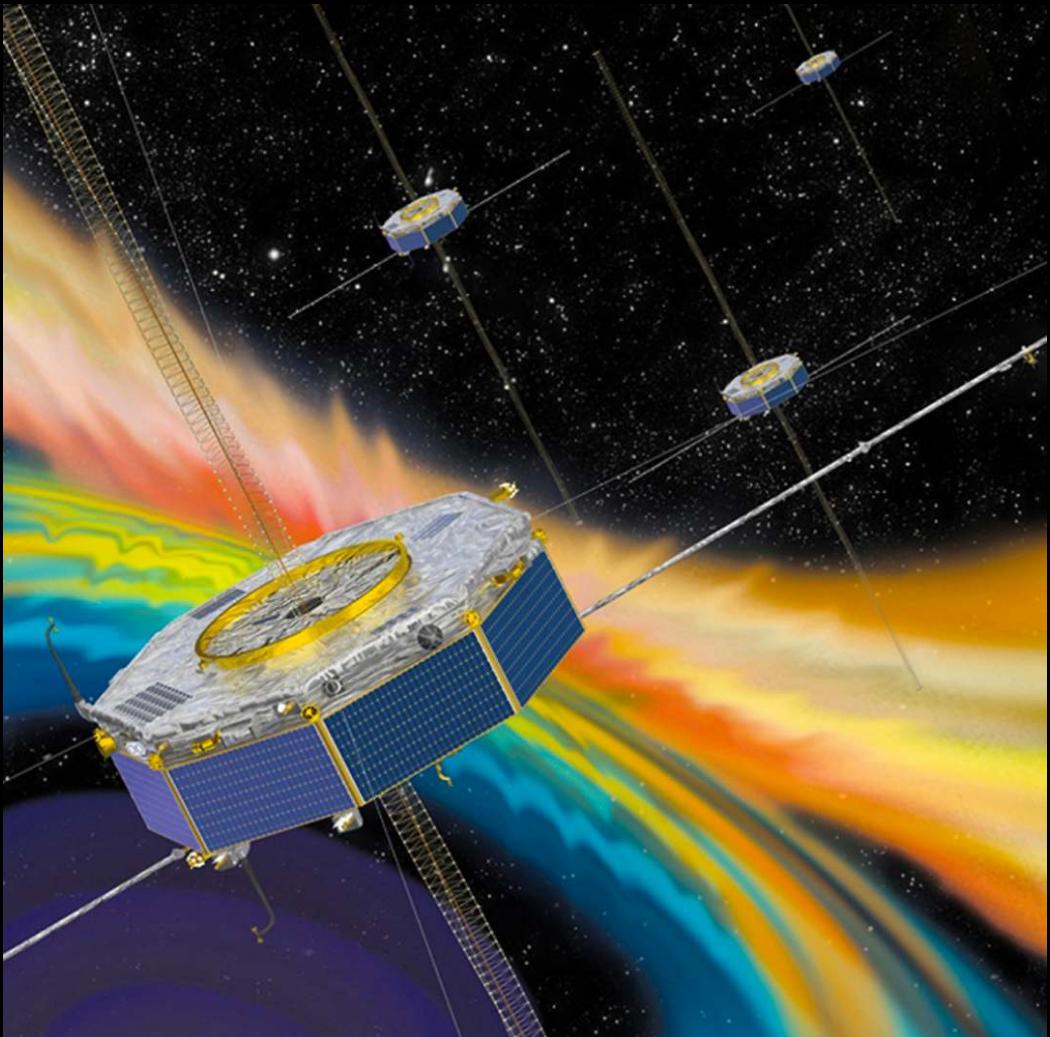
Particles are accelerated at the shock by bouncing between upstream and downstream

The acceleration mechanism is the same in all shocks in the universe



Spacecraft observations of shocks

MMS in orbit around Earth



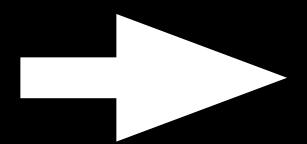
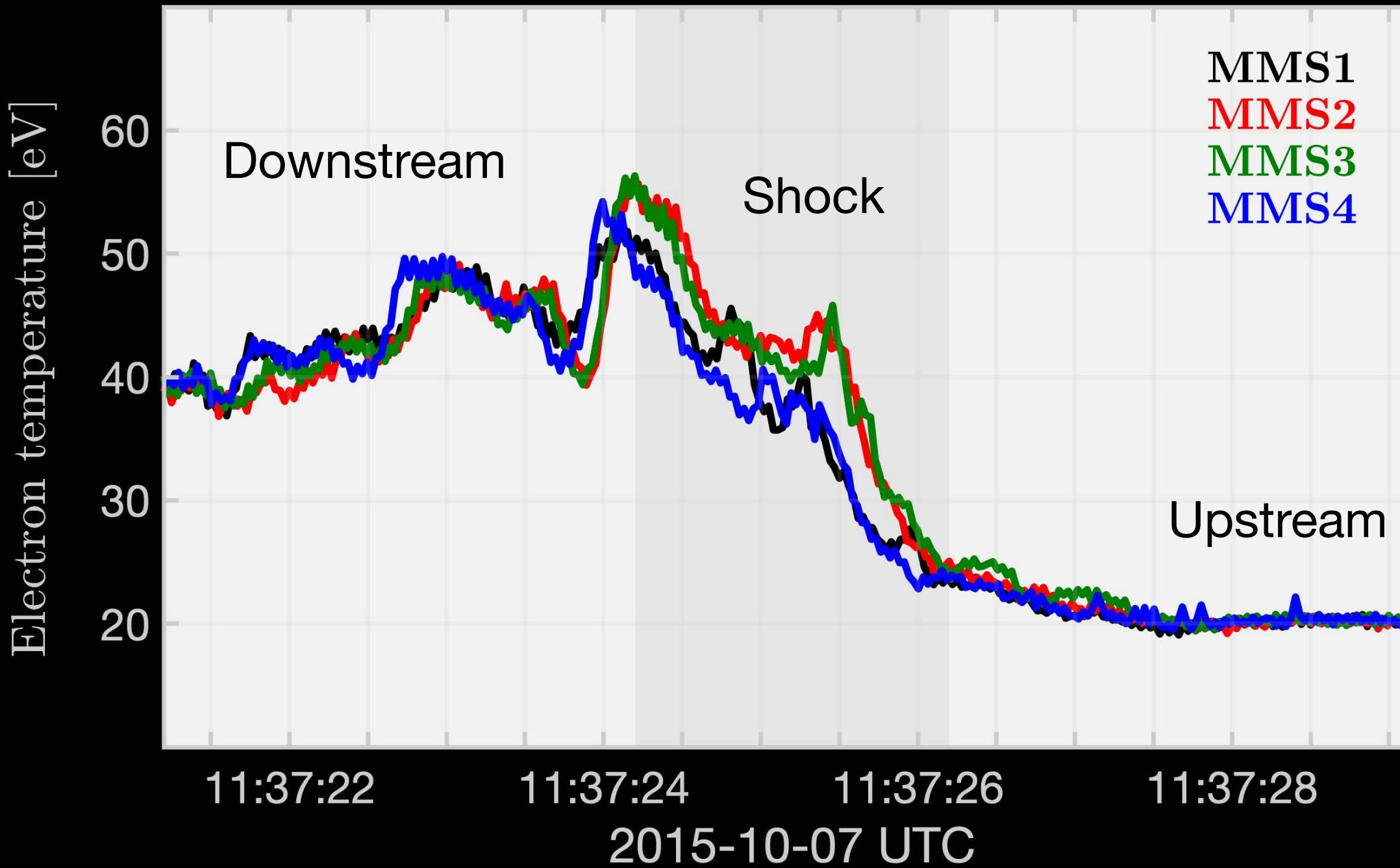
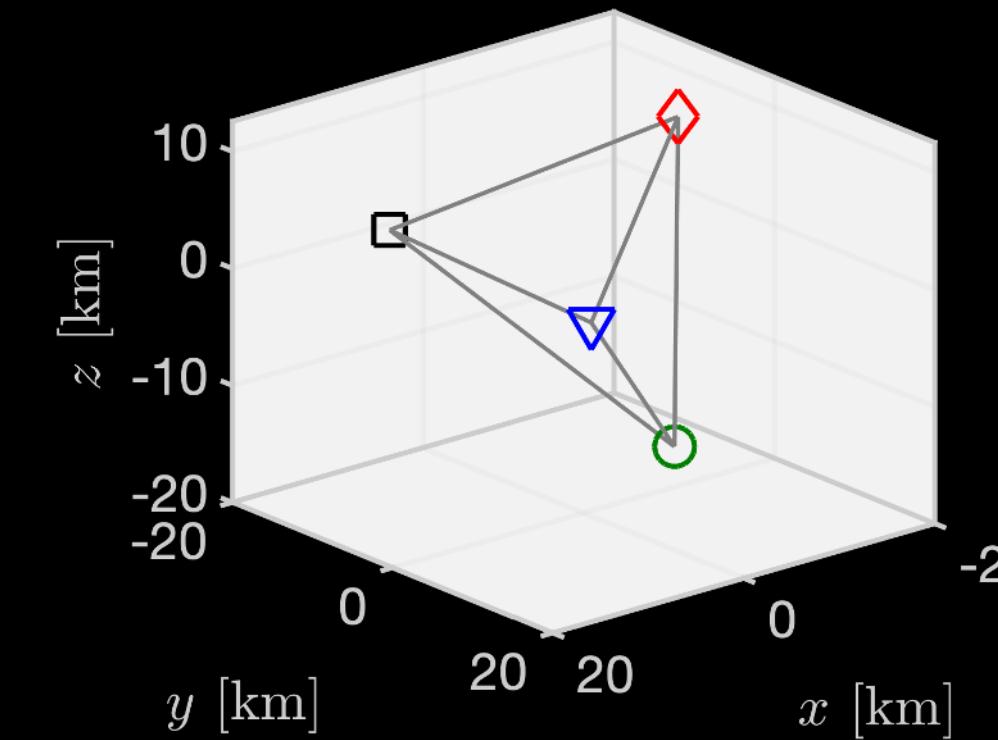
Solar Orbiter



- We use spacecraft measurements of electromagnetic fields and plasma particles to study shocks in space
- Plasma shocks around Earth and the Sun can be used as laboratories to study other shocks beyond our solar system
- We have a special interest in the small-scale structure of shocks and how they particle acceleration

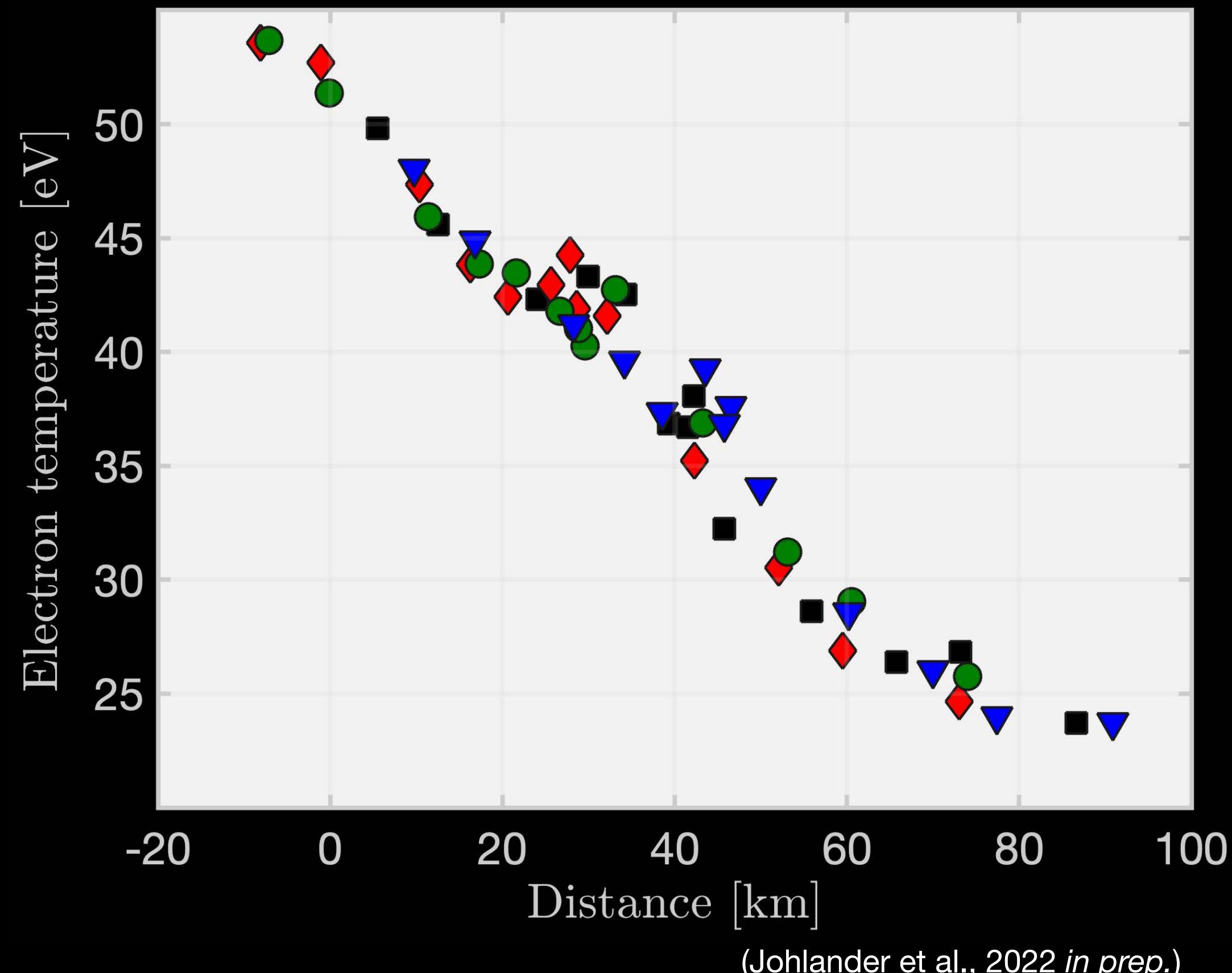
How thick are plasma shocks?

Four spacecraft are required to resolve the 3D structure of the shock



The thickness of the shock is a fundamental property which determines how particles behave.

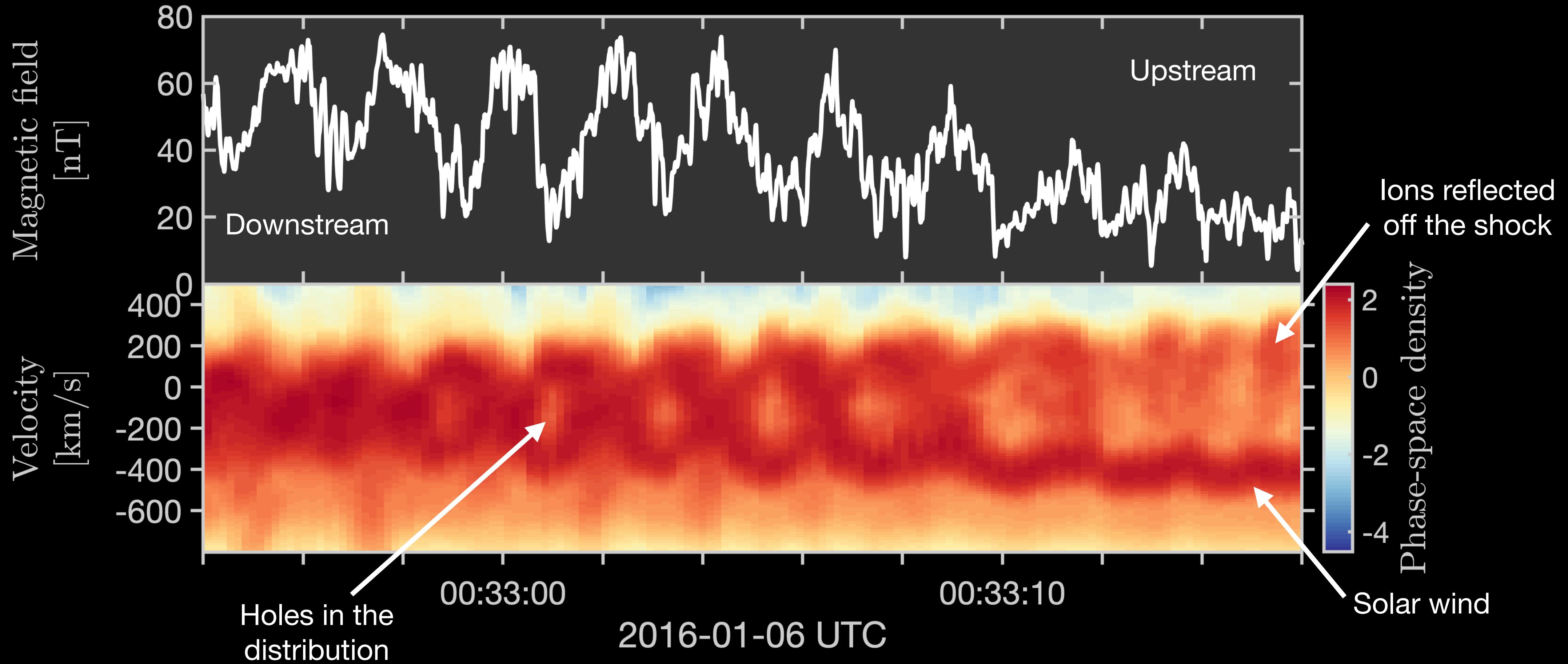
By having four spacecraft in the shock at the same time, we can measure the thickness with great accuracy



Extra slides

How do shocks evolve in time?

Fluctuations and “holes” in the ion distributions are signs that there are surface waves on the shock



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