



# Shock waves in space

# Shock waves

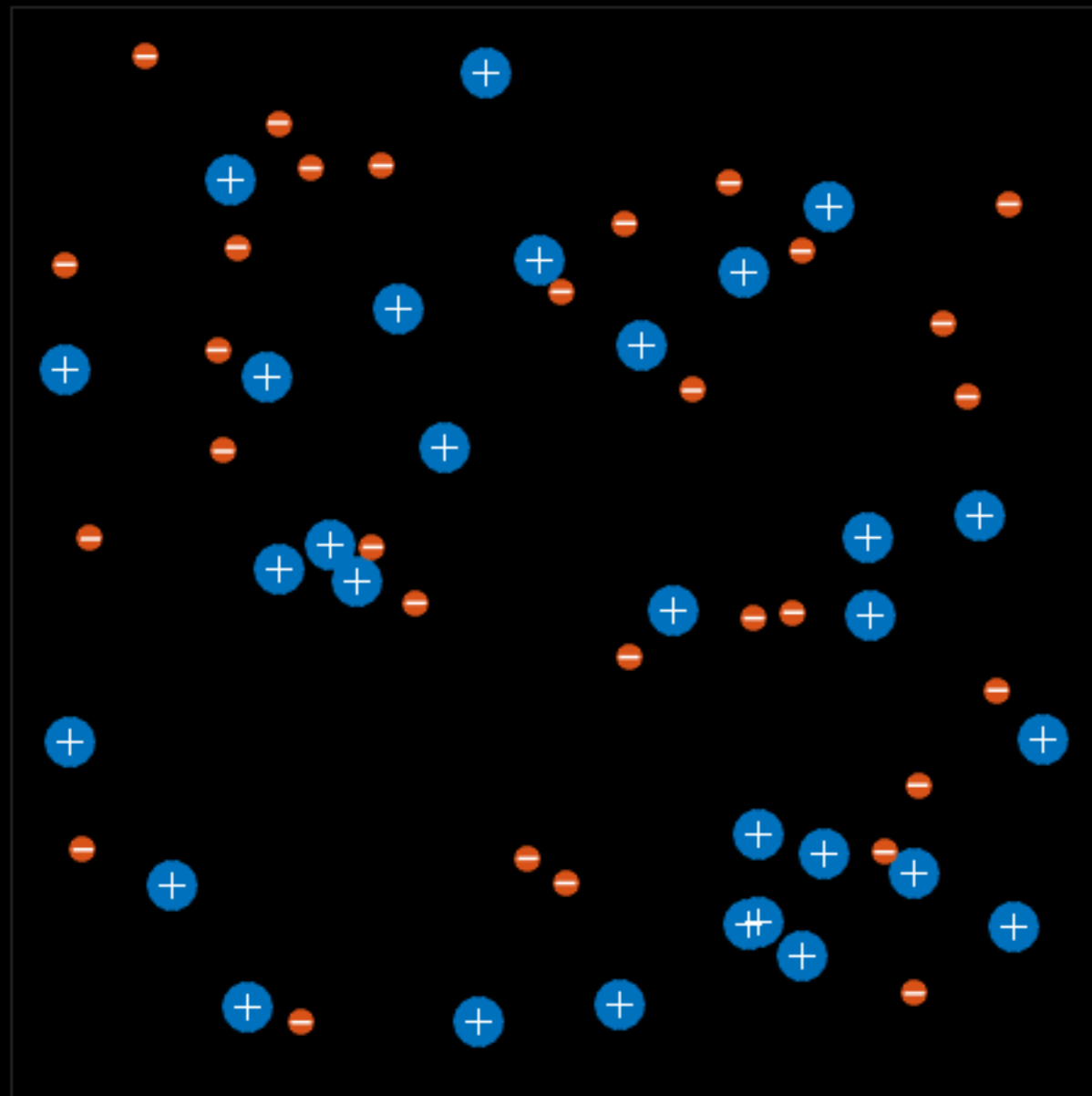
Appear when a gas flowing faster than the speed of sound encounters an obstacle



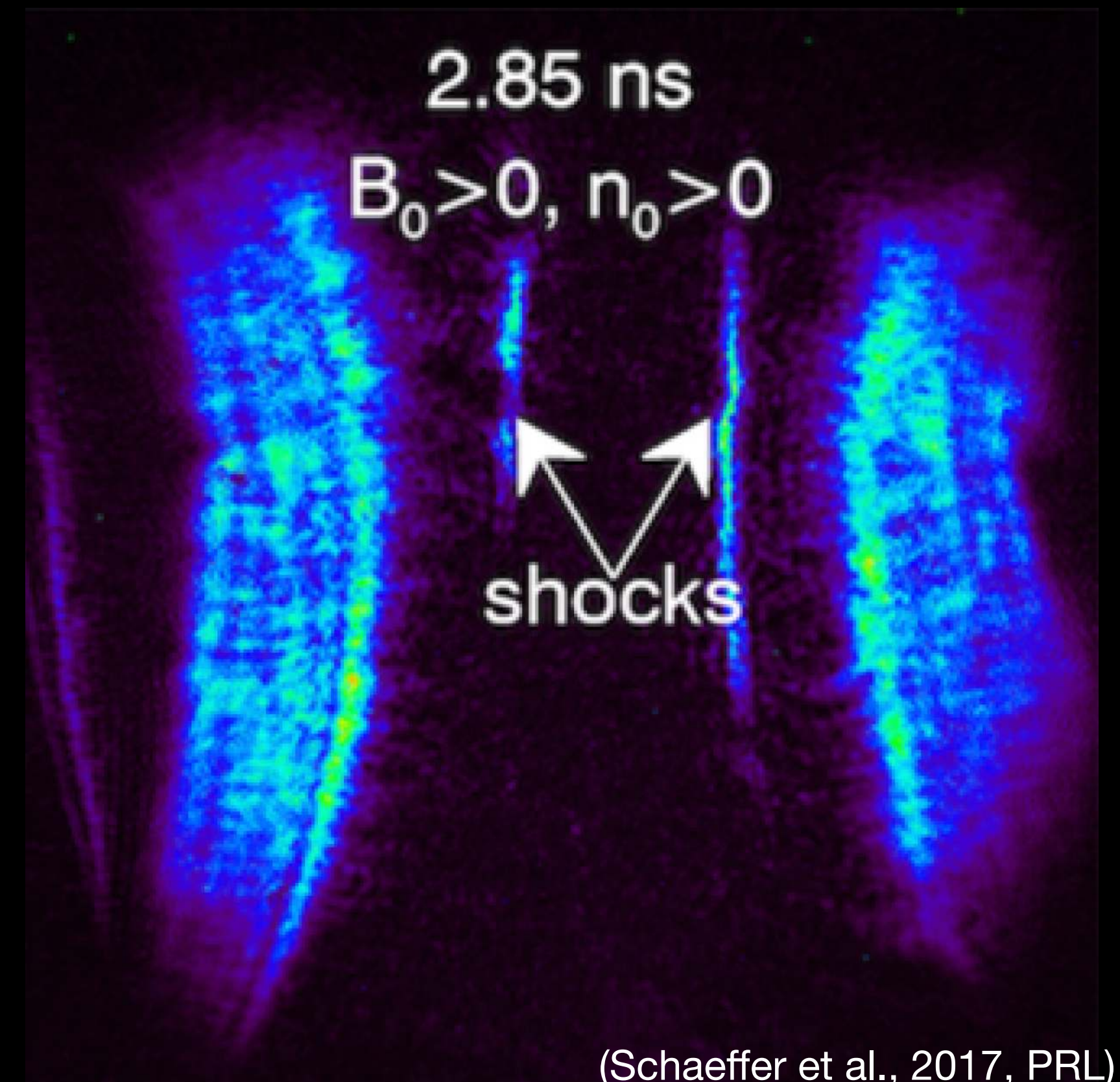


# Plasma shock waves

- 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



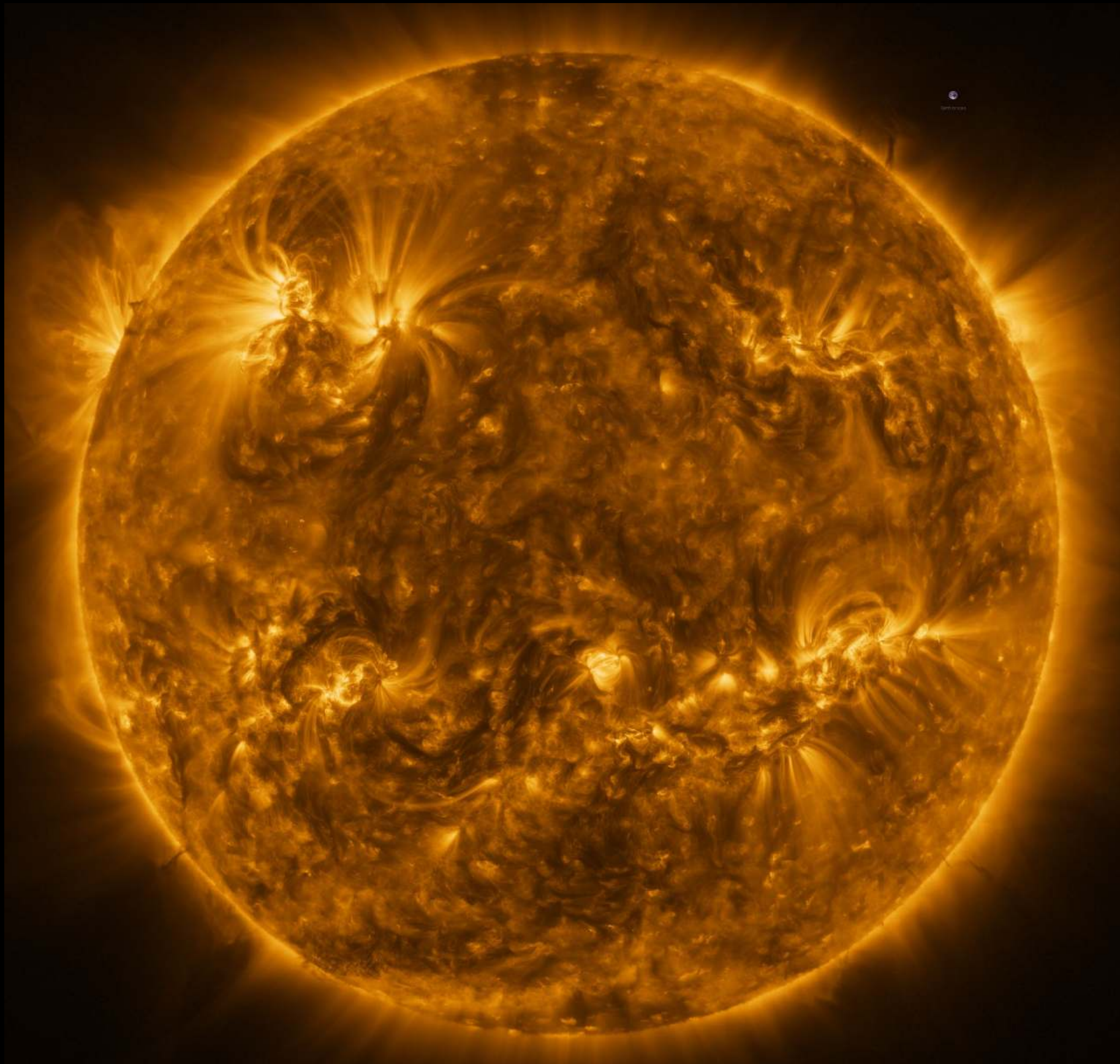
Two shock waves in a collisionless plasma obtained by shooting lasers at two opposing plastic plates



(Schaeffer et al., 2017, PRL)



# Shock waves in space



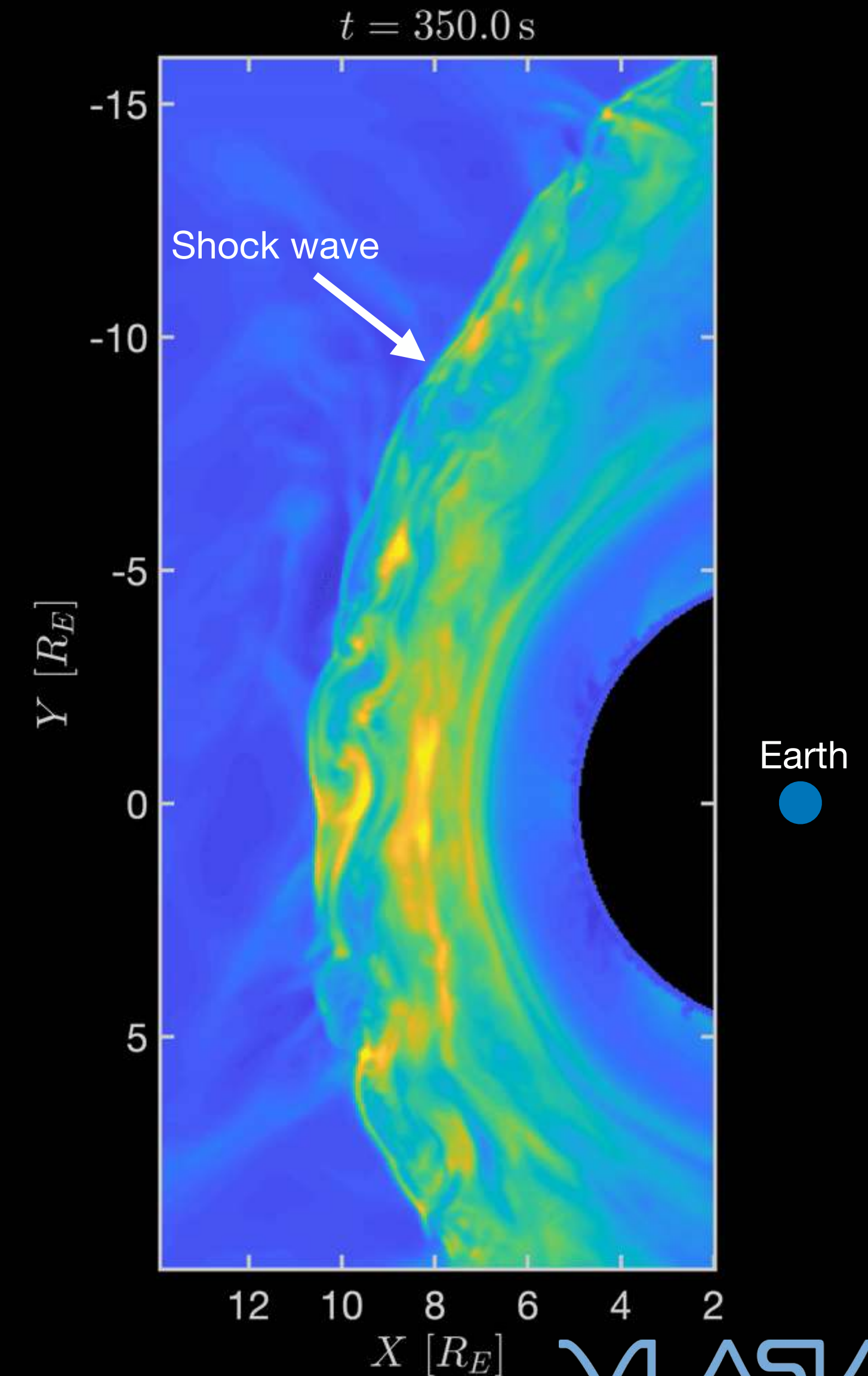
ESA/Solar Orbiter

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



Solar wind

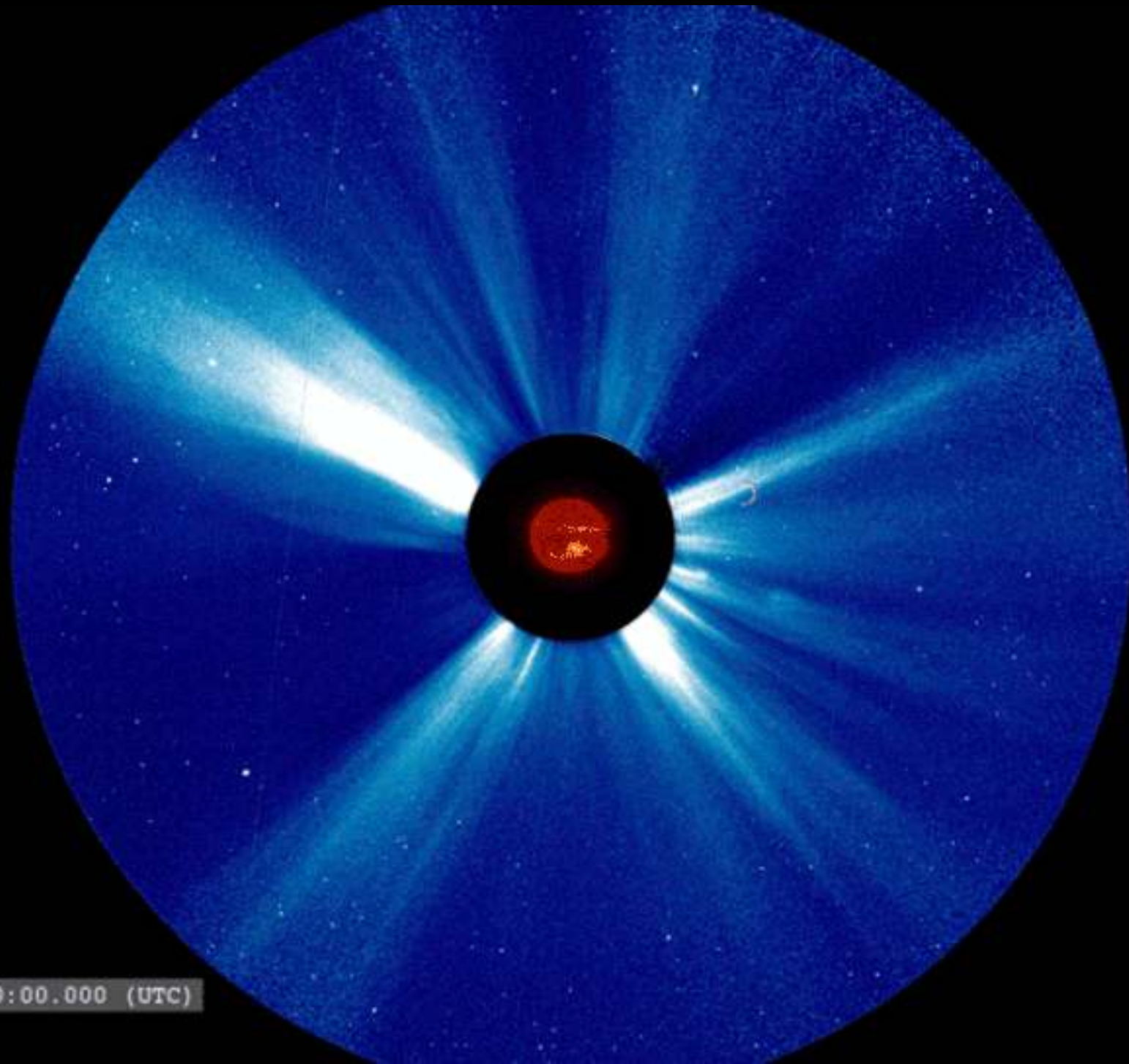
Simulation of Earth's bow shock showing plasma density





# Particle acceleration

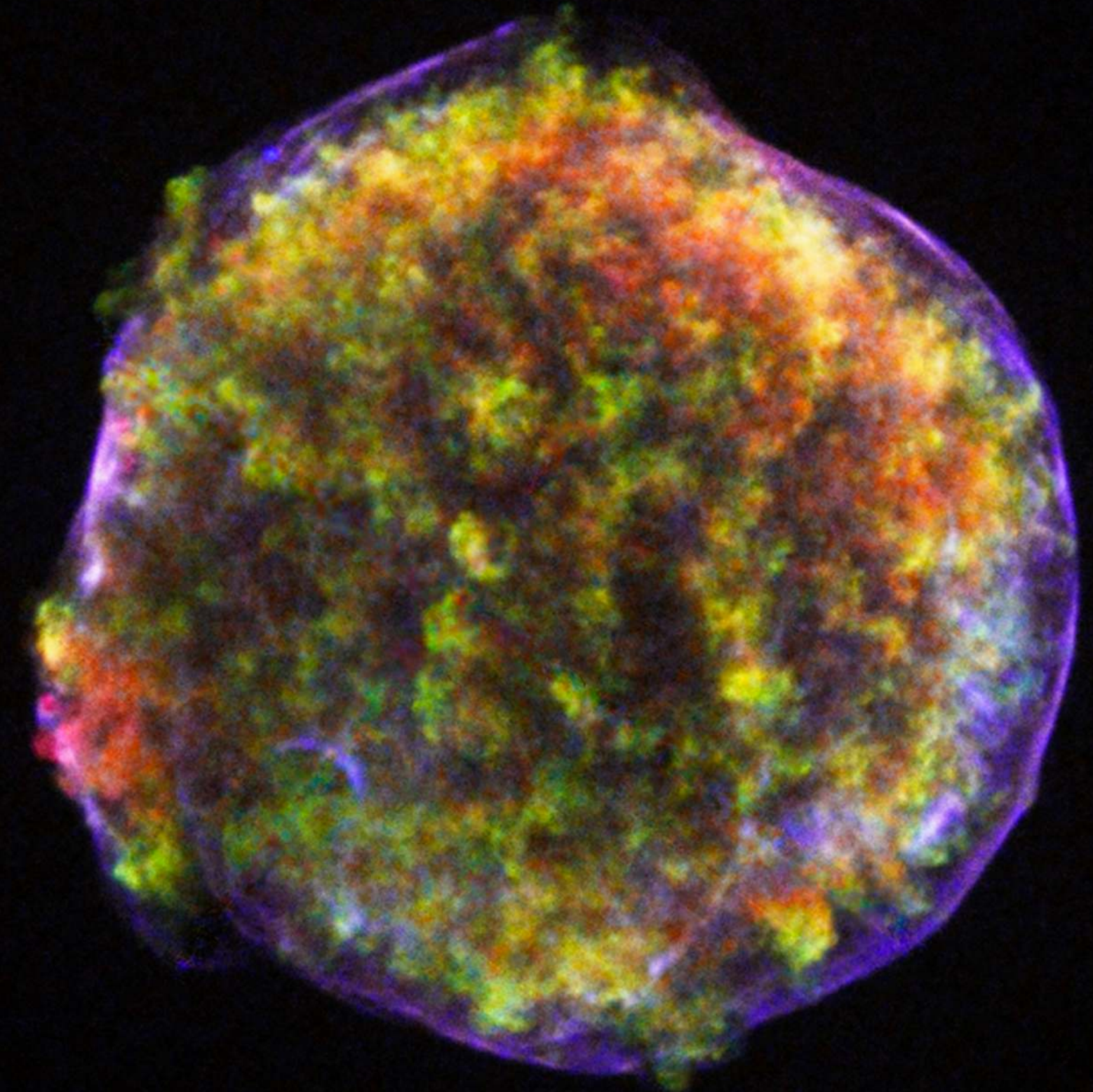
Shock waves from solar eruptions accelerate solar energetic particles which pose a threat to astronauts and satellites



2012 Jul 22 03:30:00.000 (UTC)

NASA/STEREO

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

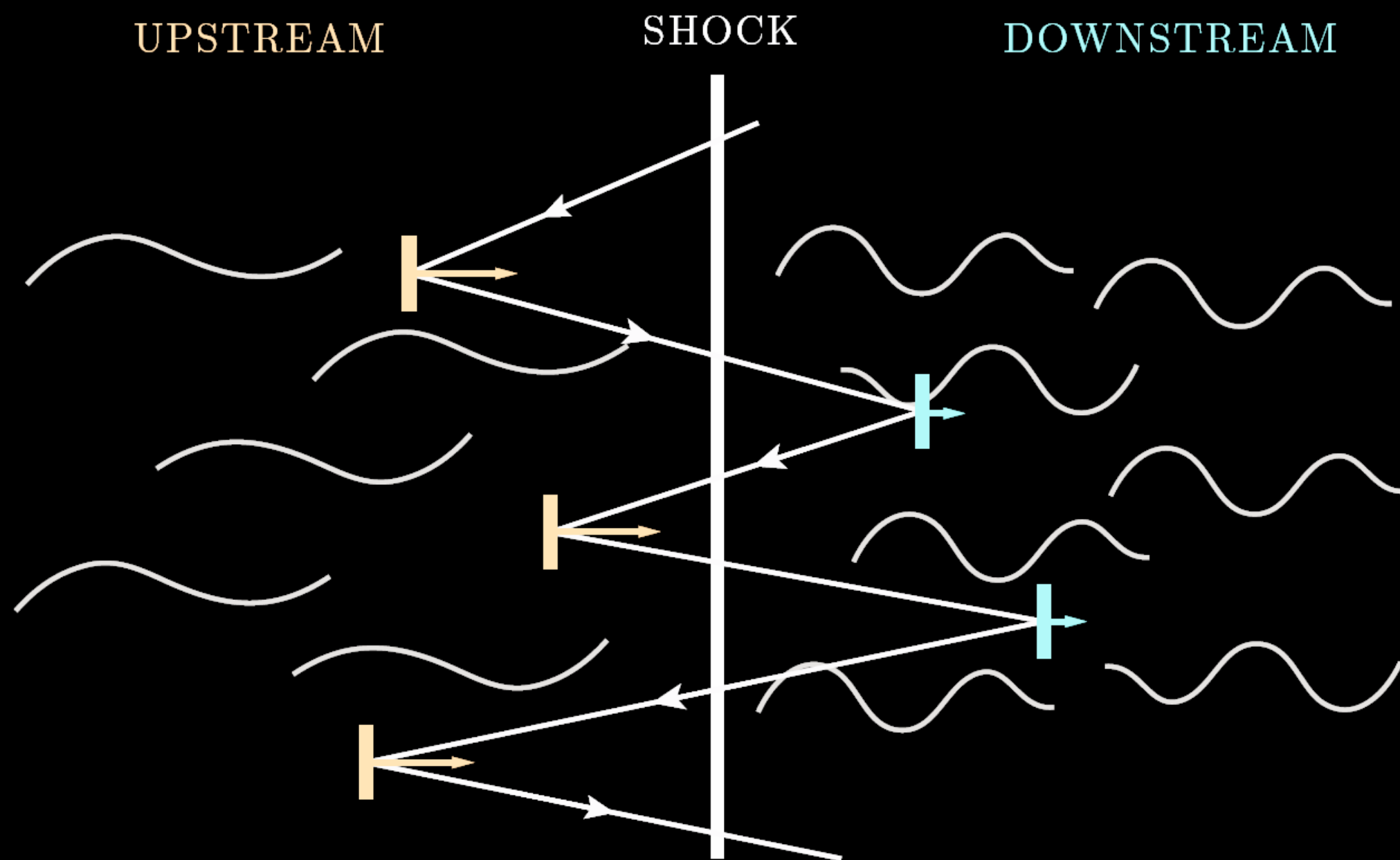


Tycho's supernova remnant in X-rays - NASA/CXC

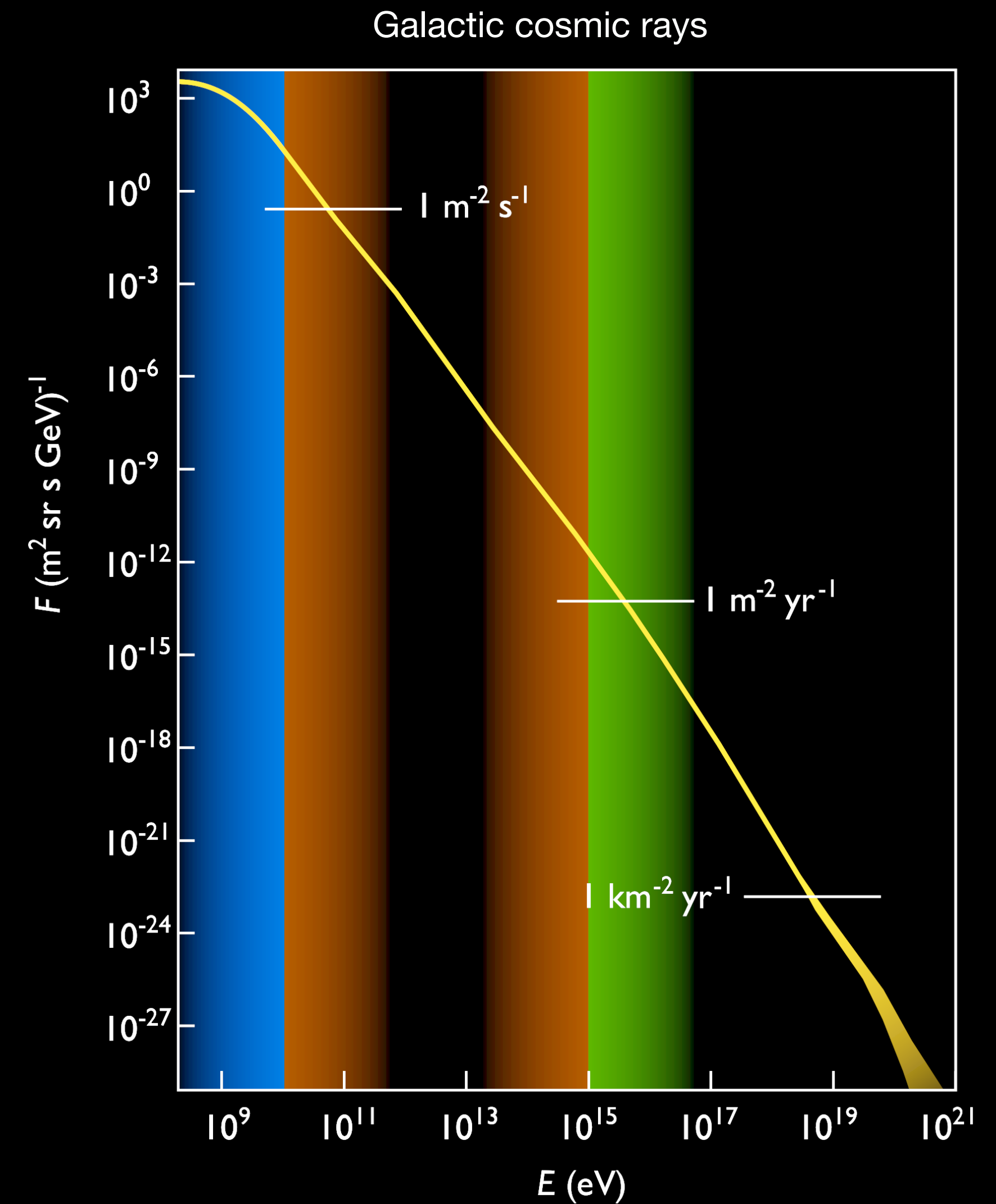


# Particle acceleration

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

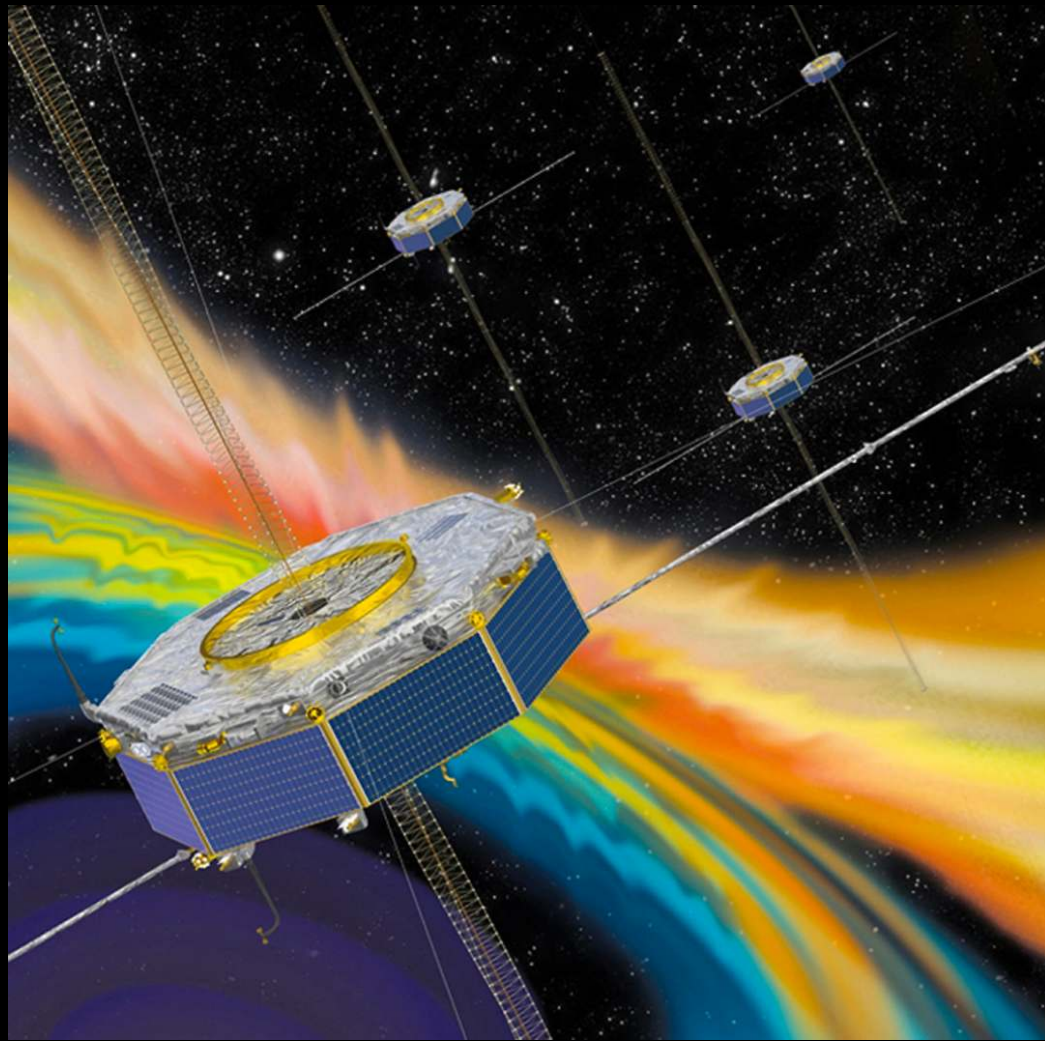


The acceleration mechanism is the same in all shocks in the universe



# Spacecraft observations of shocks

MMS in orbit around Earth



Solar Orbiter

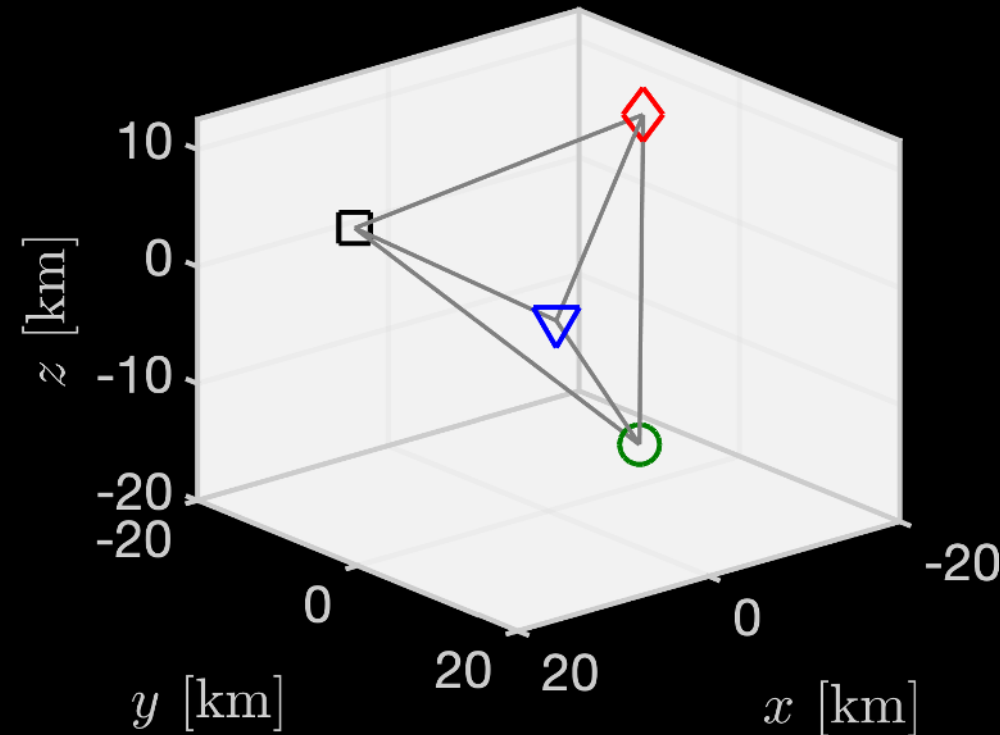


- We use spacecraft measurements of electromagnetic fields and plasma particles to study shocks in space
- Plasma shocks around Earth and the Sun can be used as laboratories to study other shocks beyond our solar system
- We have a special interest in the small-scale structure of shocks and how they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



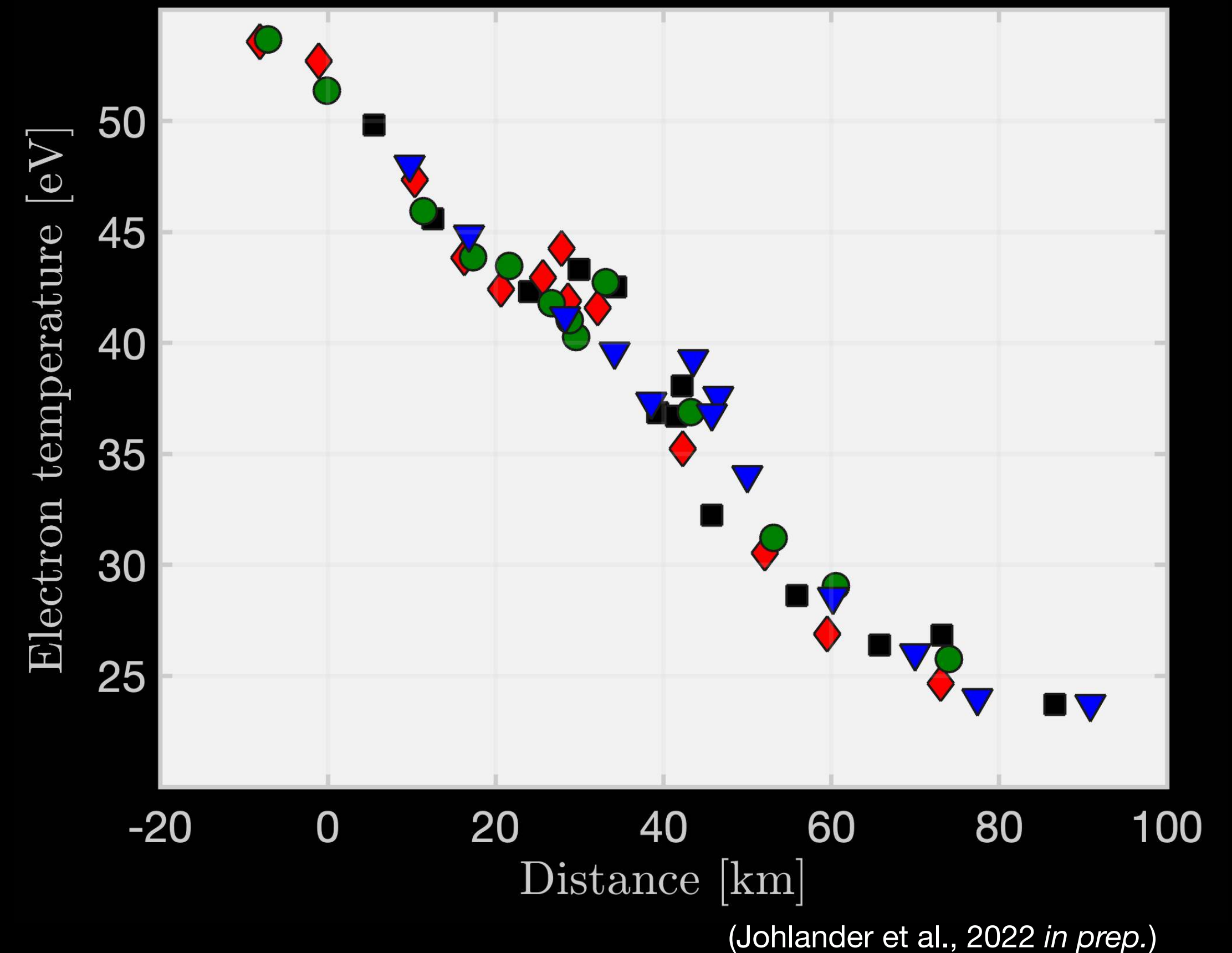
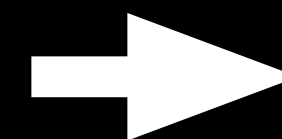
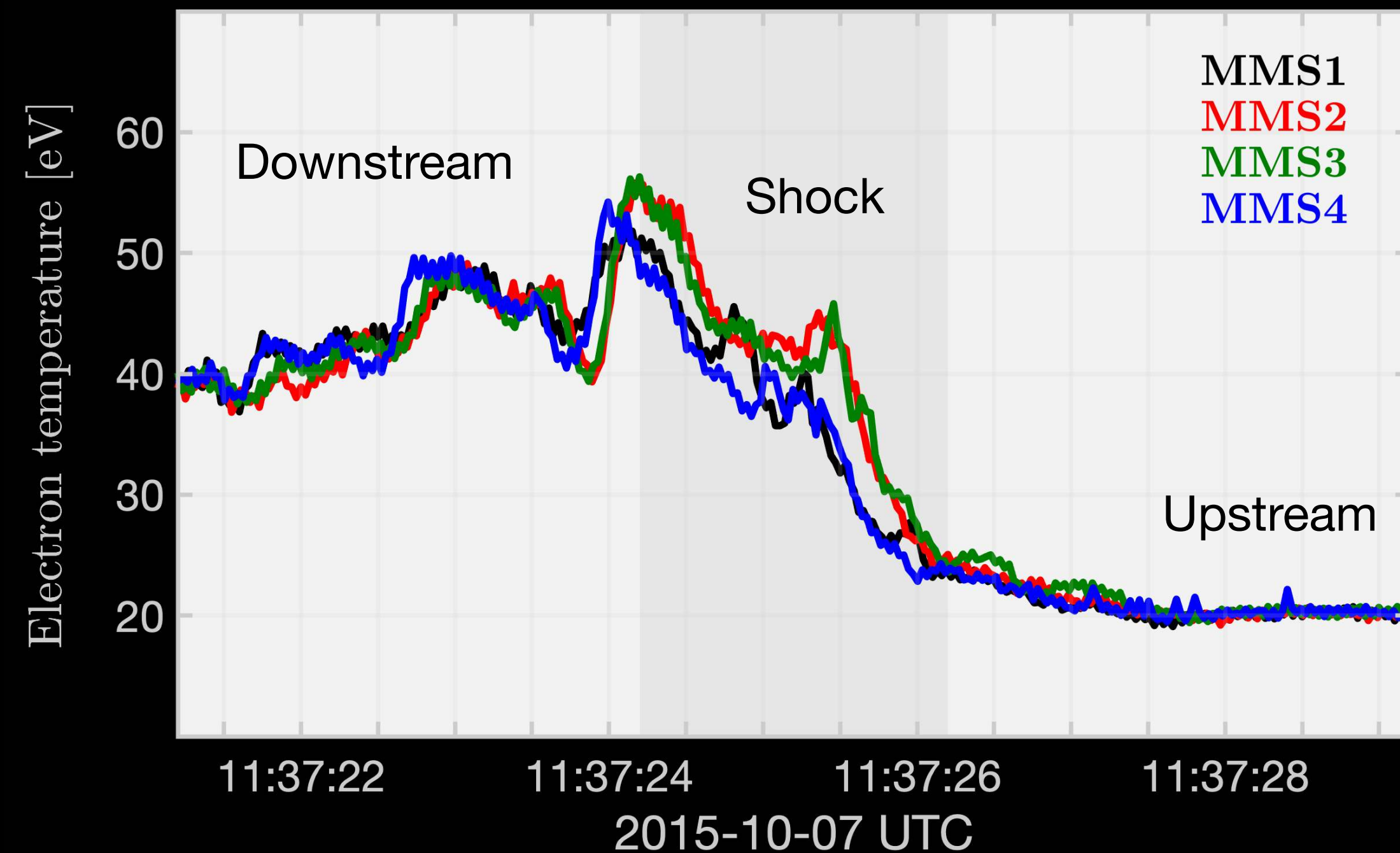
# How thick are plasma shocks?

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



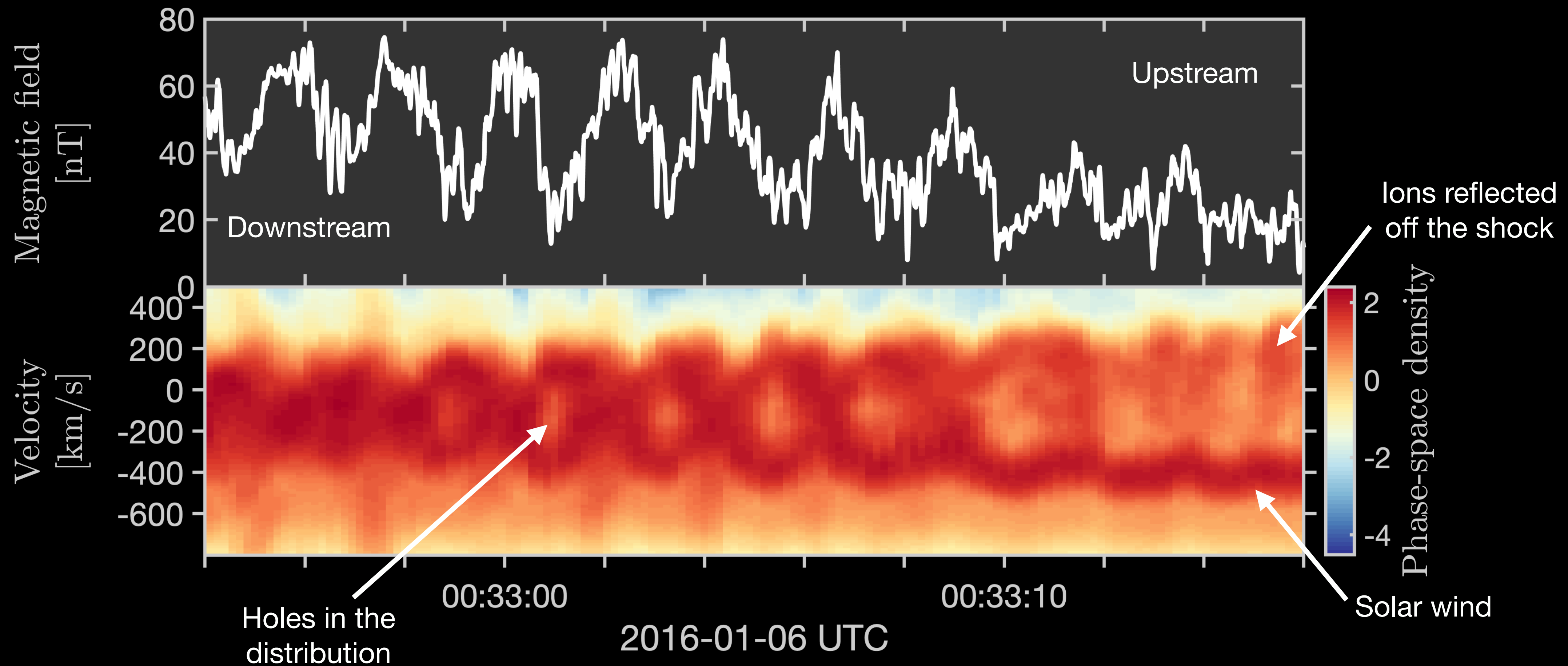


# Extra slides



# 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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