# Do shocks always accelerate ions?

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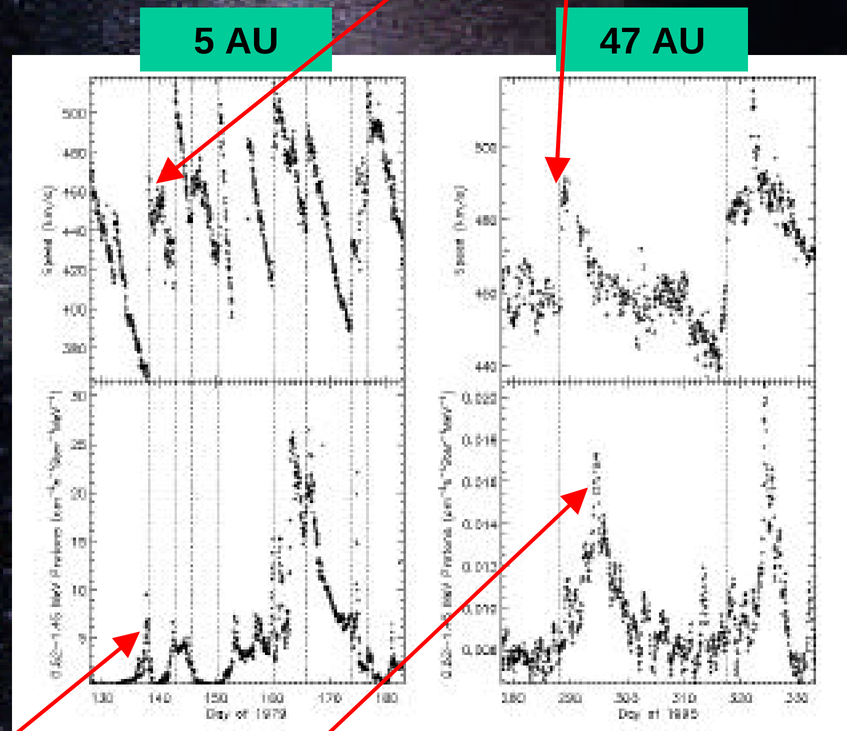
- Shocks are commonly thought to accelerate particles.
- Supported by observations of energetic particle enhancements coincident with shock waves (e.g. at 5 AU – left panel of figure).
- At 47 AU, Voyager 2 observes delays between the shock front arrival time and the energetic particle peak arrival time – right panel of figure.

**Shock front.**




**0.52 – 1.45 MeV energetic particle enhancement.**

**Supported by the Voyager Interstellar mission.**



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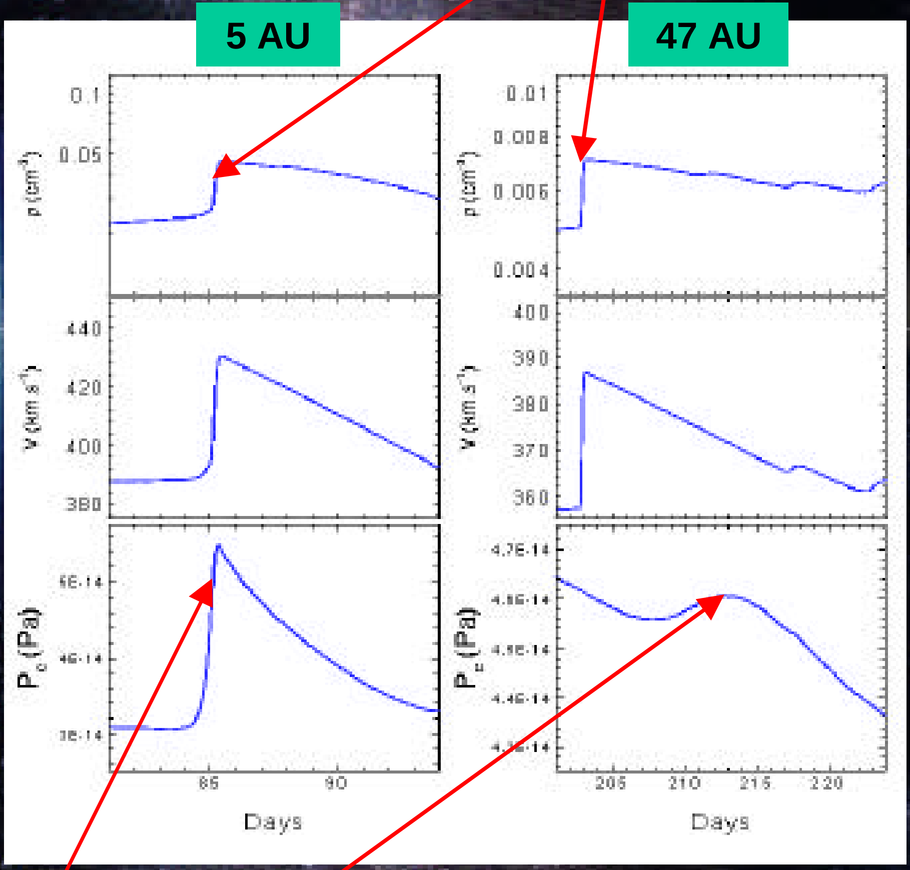
# Do shocks always accelerate ions?

We've developed a model of particle injection and acceleration at interplanetary shocks.

- Below a critical shock compression ratio (1.5) particle injection into the acceleration process (assumed to be Fermi acceleration) ceases.
- At ~ 5 AU, particle injection and acceleration at the still strong shock ensures that the energetic particles peak at the shock front (left panel of figure).
- At ~ 47 AU the now weak shock is unable to inject particles into the acceleration process and the energetic particle peak and shock front separate.

Shock front.




Energetic particle enhancement.

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- Observations in the inner heliosphere tend to show that when shocks are associated with energetic particle increases, the peak particle flux tends to coincide with the shock front.

- In the outer heliosphere, Voyager 2 data often shows a delay between the arrival of interplanetary shock fronts and the peaks in the energetic particle fluxes.

- The figure on slide 1 shows the solar wind flow speed (top panel) and the 0.52 - 1.45 MeV energetic particle flux (lower panel) measured by Voyager 2 at 5 AU (left hand side) and at 47 AU (right hand side).

- Shocks are indicated by the vertical dashed lines. At 5 AU the shocks and peaks in the energetic particle flux are essentially coincident.

- At 47 AU, the peaks in the energetic particle fluxes lag the shock fronts by about 7 days.

- We model this using a 1-D model in which shock waves can be included.

- Energetic particles are modeled using the cosmic ray transport equation.

- At the shock fronts we convert a certain amount of solar wind internal energy into energetic particle energy (injection). These particles can then be further accelerated via Fermi acceleration.

- Below a certain critical shock compression ratio (taken to be 1.5) we assume that the shock is no longer able to inject particles into the Fermi acceleration process.

- Since scattering is taking place, energetic particles tend to convect with the solar wind while they diffuse.

- The shock and energetic particle peak therefore tend to separate as the shock propagates faster than the solar wind flow speed.

- The figure on slide 2 shows the solar wind density (top panel), flow speed (middle panel), and energetic particle pressure (lower panel) at 5 AU (left hand side) and at 47 AU (right hand side). On the x-axis we plot the approximate number of days it takes the structure to reach the observer at either 5 AU or 47 AU.

- At 5 AU the shock is strong and is injecting and accelerating particles. The energetic particle peak is therefore coincident with the shock front.

- At 47 AU, the shock is much weaker, has not been accelerating particles for quite some time (injection turned off at ~ 35 AU) and the shock front leads the energetic particle peak by about 8 - 10 days.

- The implications of this results is that shocks may indeed become too weak to inject particles into the shock acceleration process. It is also further evidence that some form of injection is needed before Fermi acceleration can take place at a shock (unless a superthermal population of particles already exists). Further, there has been a suggestion that anomalous cosmic rays may be produced by particles accelerated at the solar wind termination shock after being pre-accelerated at interplanetary shocks. The result presented here may have some implications for this idea.