Shocks

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Big Subject!

- Lessons from the Earth’s bow shock
- Inwards and outwards in the Heliosphere
- Going further …

Shocks in General

- Simplest (and most complicated) nonlinear waves
- Conservation relations for upstream to downstream make them simple
- Flow energy converted to thermal
- Collisionless processes make them complicated!

Collisionless Shocks

- Heating via field-particle interactions
- Nonthermal distributions
- Energetic particles – of all kinds
- A small fraction of flow energy may end up as very energetic particles
- Foreshock and downstream turbulence

Terrestrial Bow Shock

- Detailed observations over 40 years
- Advances in understanding collisionless plasma shocks
- Shock is usually high Mach number
- Importance of shock magnetic geometry: perpendicular to parallel
- A small-ish obstacle, important curvature

Shock Structure from Observations

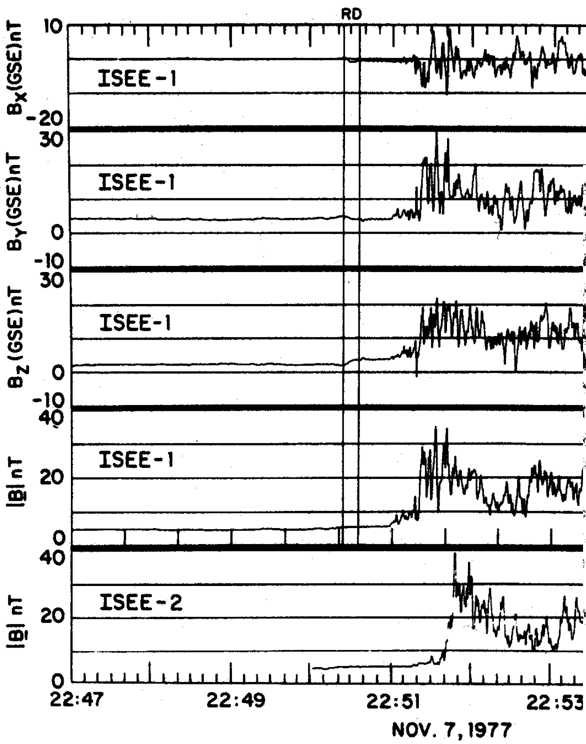


Fig. 2. The magnetic field observed during and near the shock crossing whi The RD observed on ISEE 1 is illustrated in the ISEE 1 components. The top tl the field observed on ISEE 1, and the lower two panels show the field magr respectively. The data have been averaged to a resolution of 0.5 s.

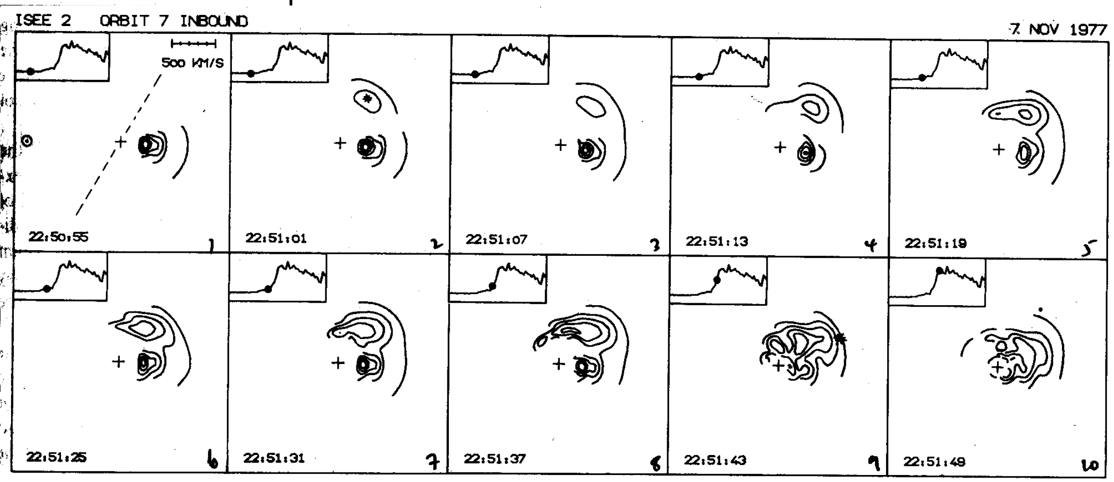
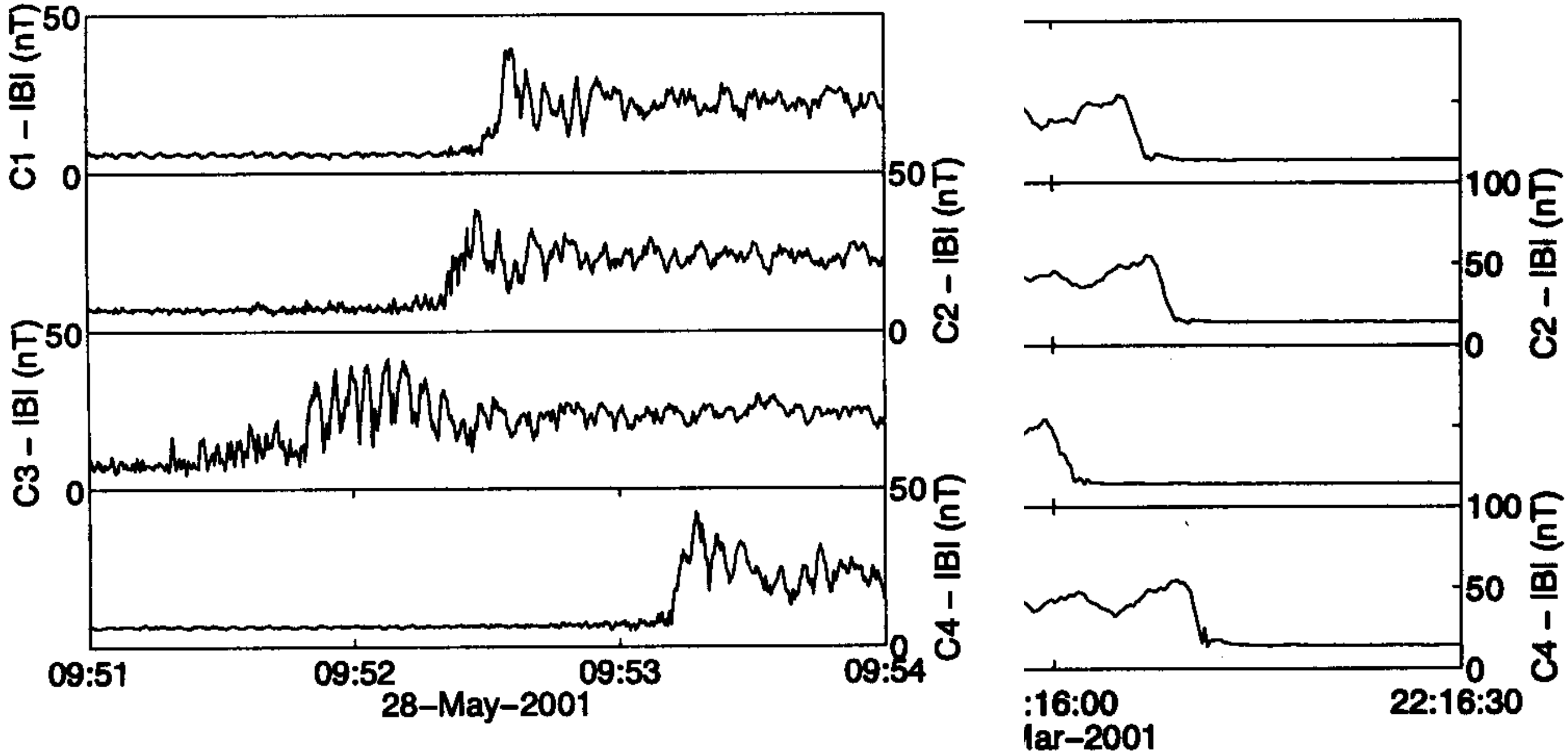


Fig. 2. Ion velocity space distributions for the inbound shock crossing on November 7, 1977, spanning the range from the pure solar wind to the shock ramp. To emphasize the evolution of the distributions, only every other of those measured is shown. The relative positions where the measurements were made are indicated by the dots on the plasma density profiles shown as insets that cover an interval of 2.5 min. The distributions are shown as contours of constant phase space density in two-dimensional velocity space, $f(v, \phi) = \text{const}$, where v is the ion speed and ϕ is the ecliptic azimuth of the velocity vector, with $\phi = 0$ pointing toward the sun on the left. Density levels represented by adjacent contours differ by an order of magnitude. The plus symbols indicate the coordinate origin $v = 0$ in the spacecraft (or, approximately, the shock) frame of reference with the velocity scale given in the first frame. The dashed line in this frame is the projection of a vector parallel to the shock front and perpendicular to the magnetic field, onto the ecliptic plane. The asterisks in frames 2 and 9 indicate the speed and azimuth of specularly reflected ions at their forward turning point and near the shock ramp, respectively.

Cluster Observations



Quasi-Parallel Shock

- Important for particle acceleration
- Role of shock structure for "injection"

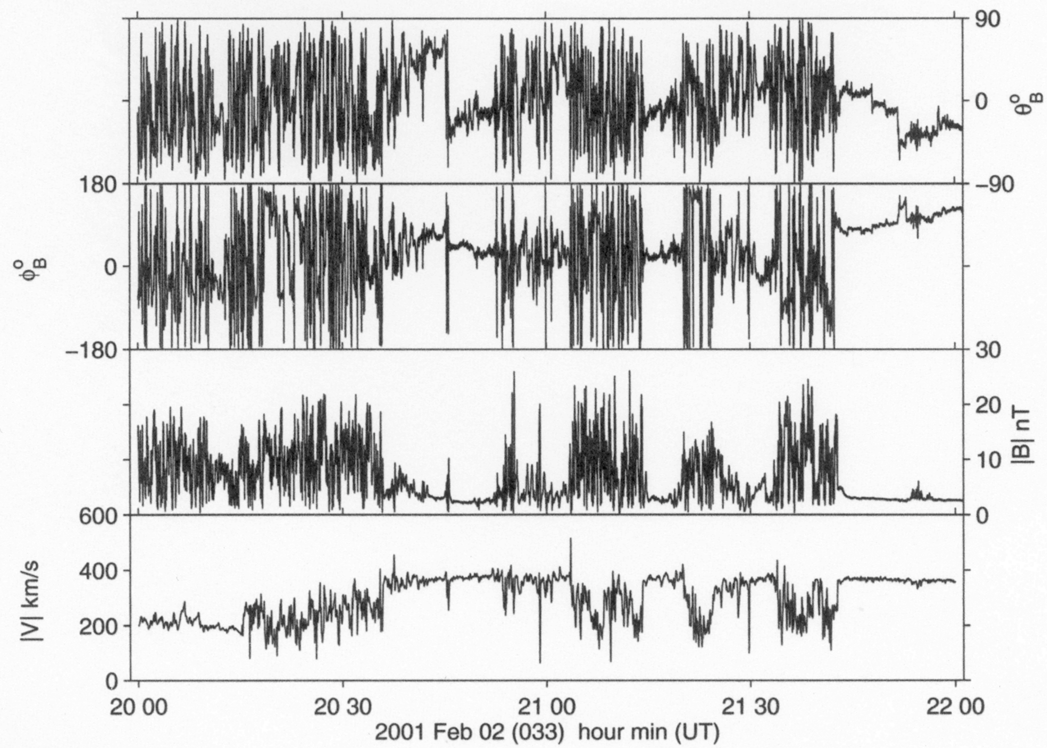


Figure 0.1. Magnetic field and velocity data recorded through a parallel shock crossing on February 2 2003. Data are from Cluster 1. Panels show magnetic field (θ) and elevation (ϕ) angles in degrees, plotted in GSE co-ordinates, magnetic field magnitude $|B|$ (nT), and plasma velocity $|V|$ (km/s). Cluster starts the interval in the magnetosheath, observes several shock crossings, and by the end of the interval is in the solar wind.

Pulsations within Shock Transition

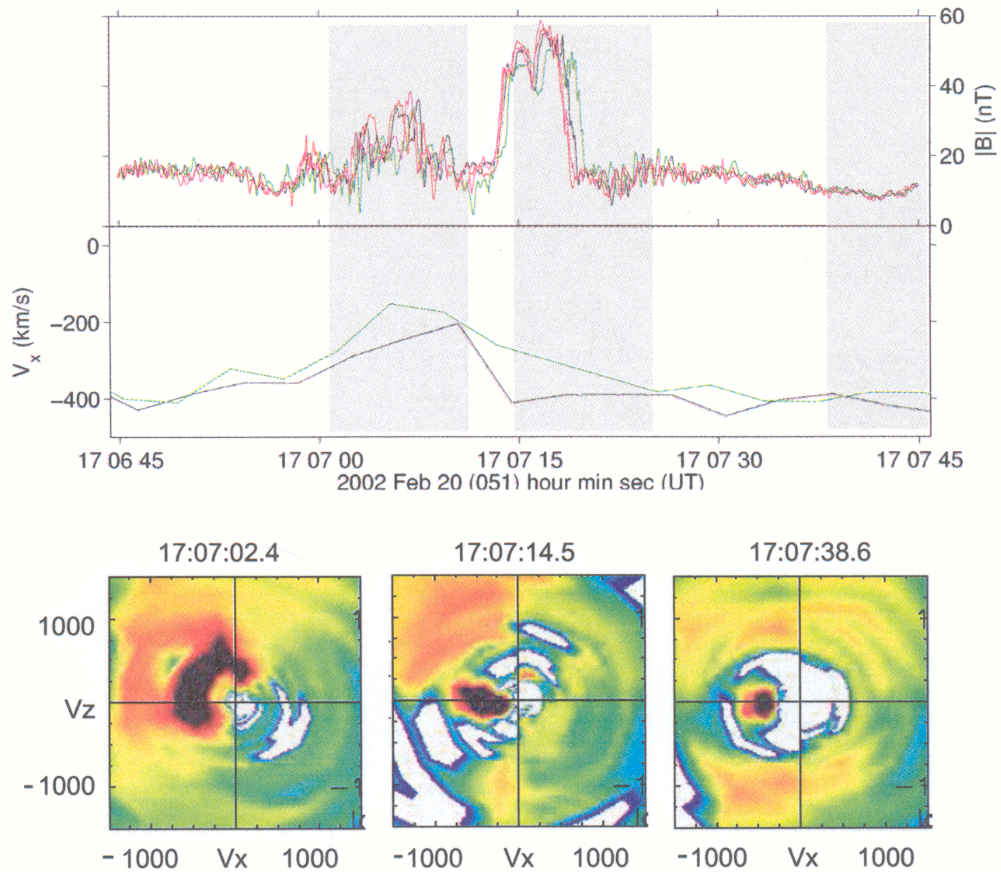
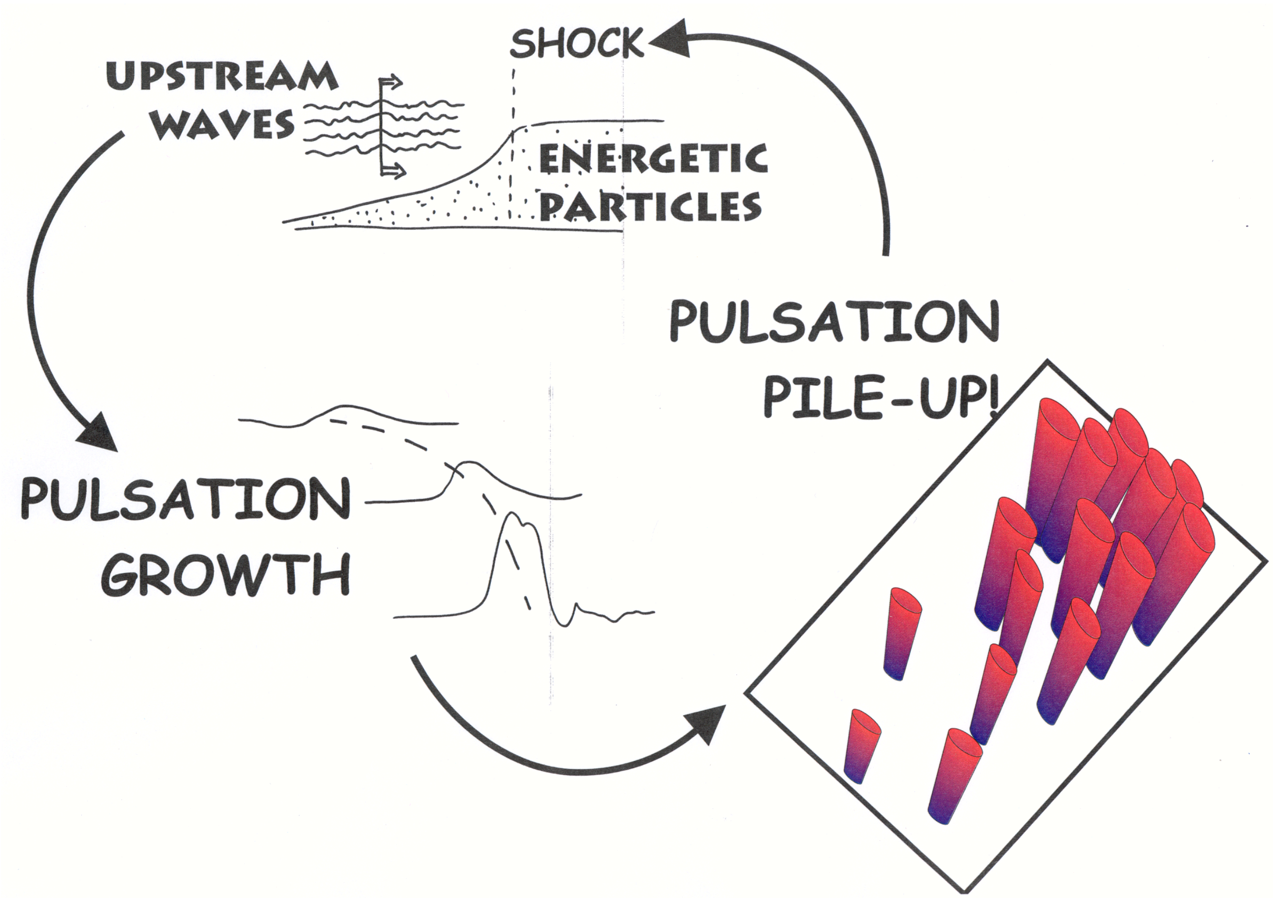
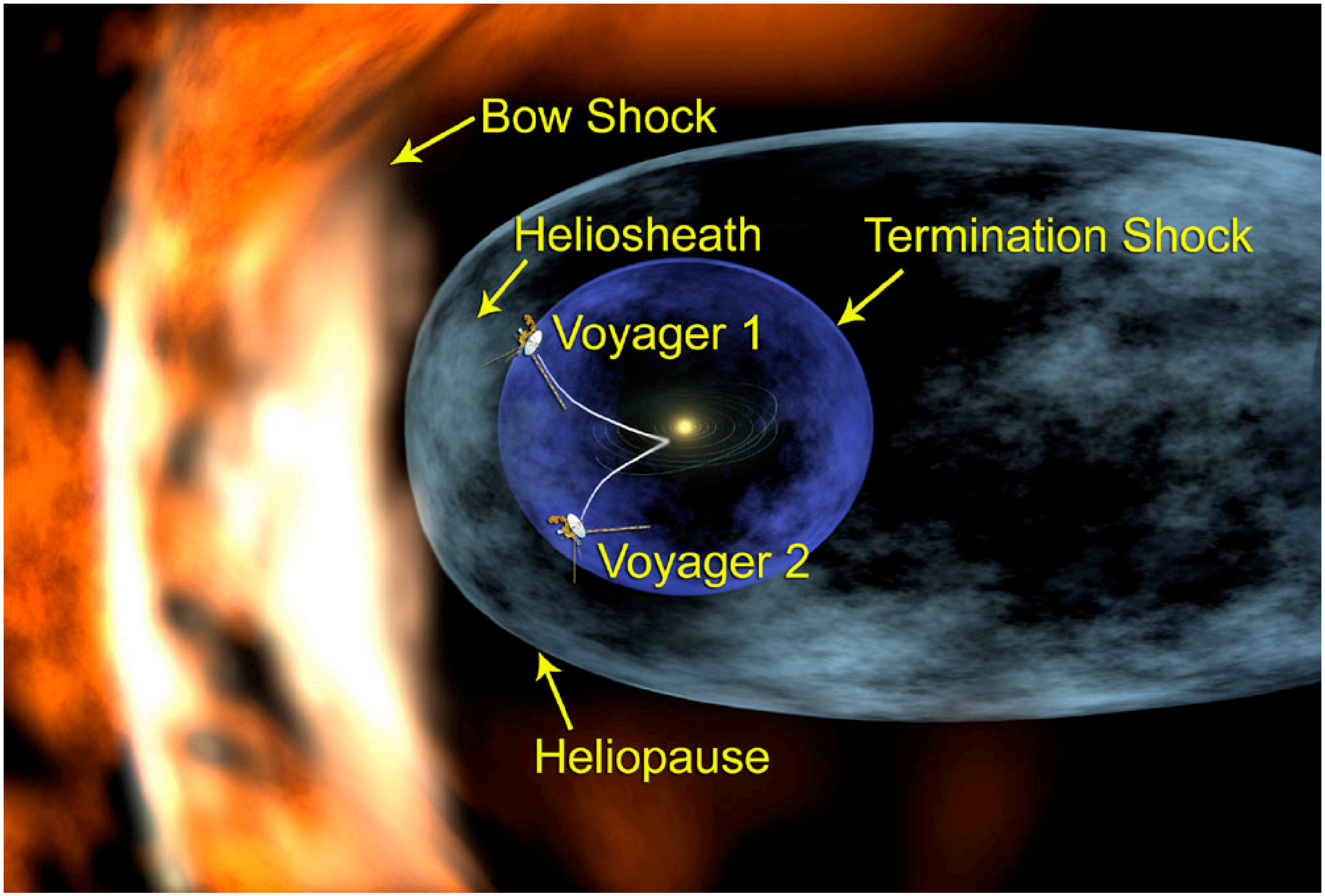


Figure 0.4. Ion reflection associated with SLAMS. The top two panels show magnetic field magnitude and plasma velocity in the X_GSE direction. The three shaded areas show the approximate times over which the three ion distributions shown below were accumulated. Each ion distribution shows ion flux plotted on a colour scale where blue and green indicate low fluxes, and black indicates high flux. Each distribution is a cut through $V_Y(GSE) = 0$ and shows V_X on the ordinate and V_Z on the abscissa.

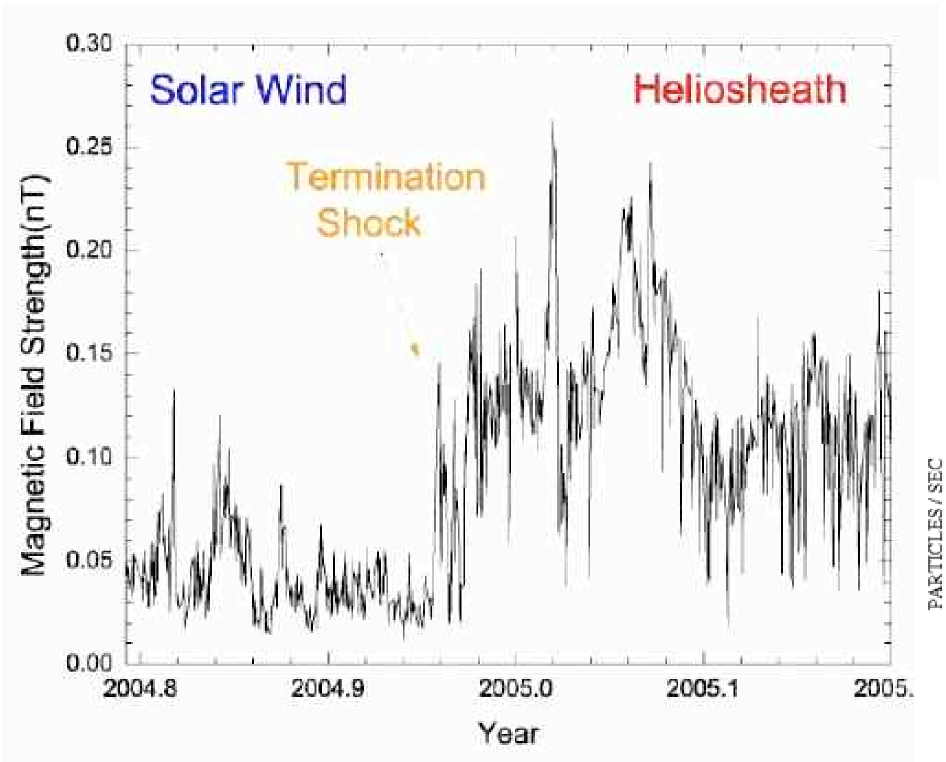
Model of Quasi-Parallel Shock

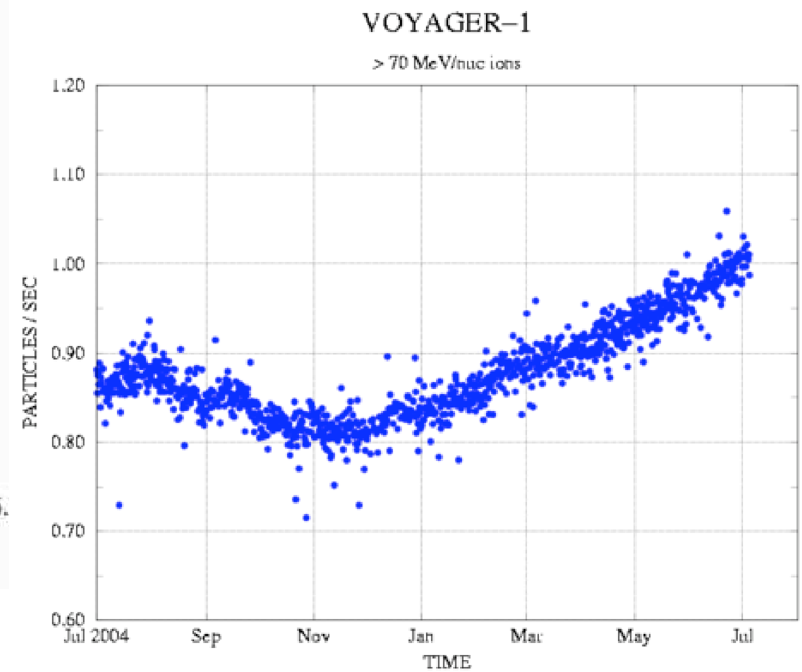


Outwards to the Termination Shock



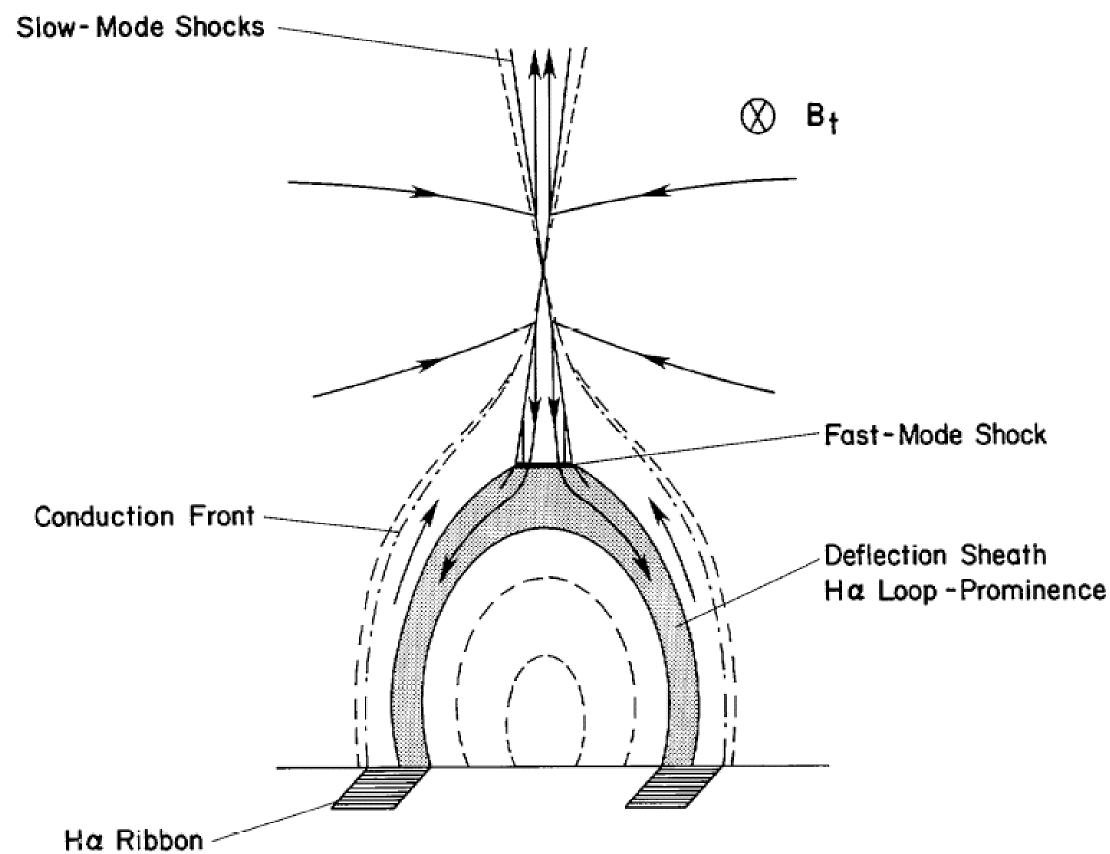
The edge of the heliosphere …





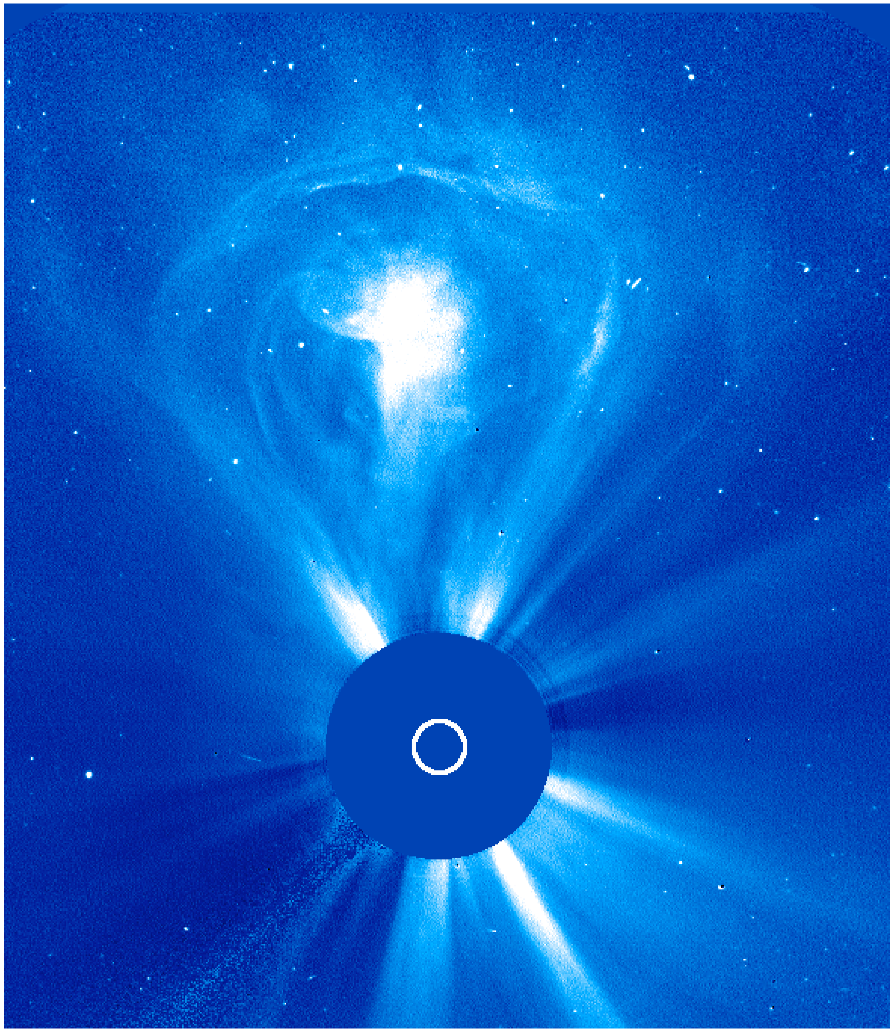
Inwards to the Sun

Flares …



Solar shocks continued …

CME



More solar shocks?

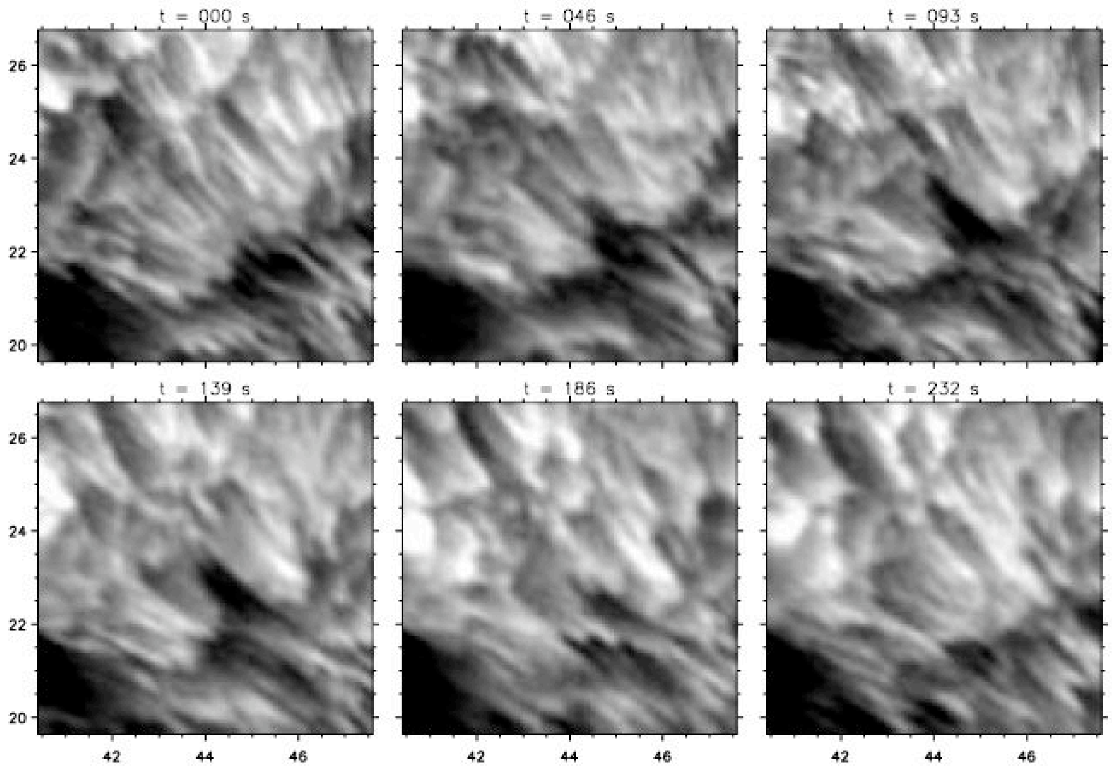


FIG. 4.—Snapshots in Hα line center that show the temporal evolution of a DF as it rises and retreats. This DF is thin, short, and highly dynamic. It shows some evidence of substructure during its evolution. It is located in region 2. [*This figure is available as an mpeg animation in the electronic edition of the Journal.*]

Dynamic Fibrils - Simulations

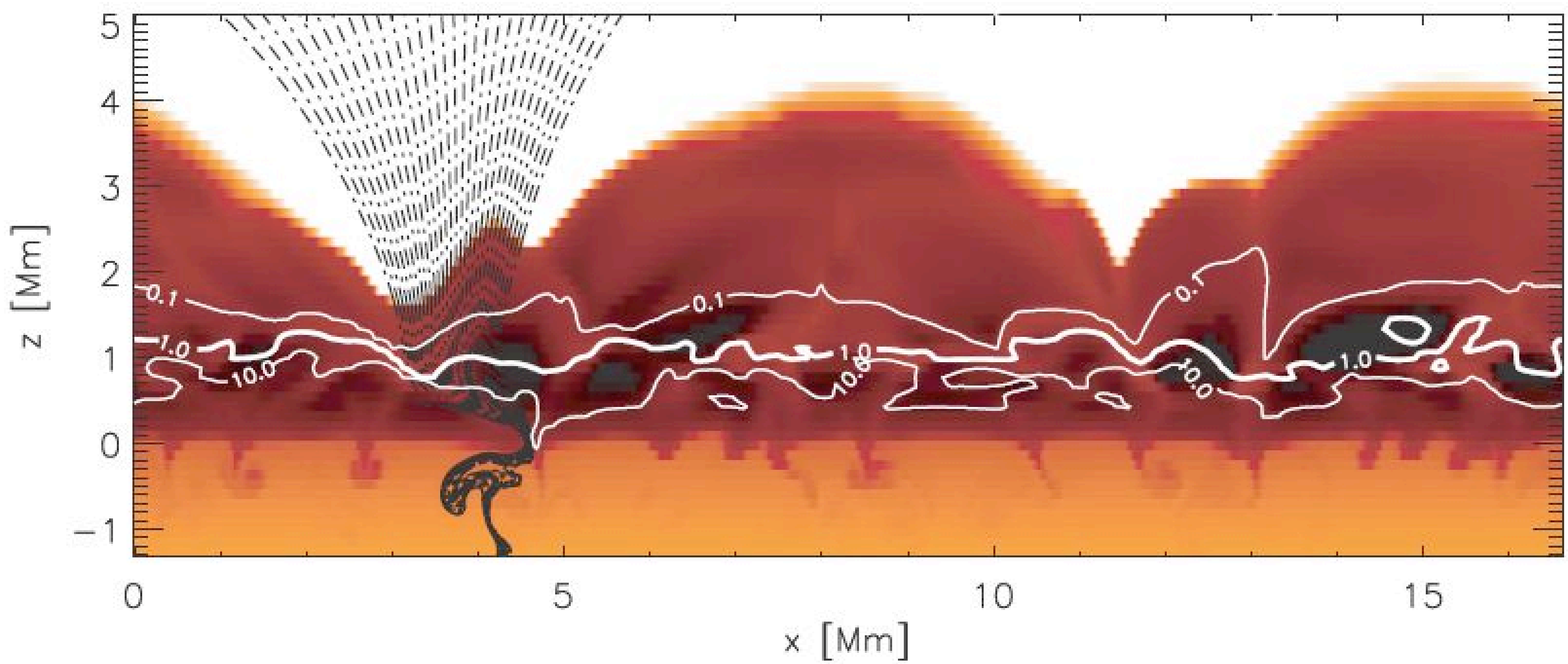
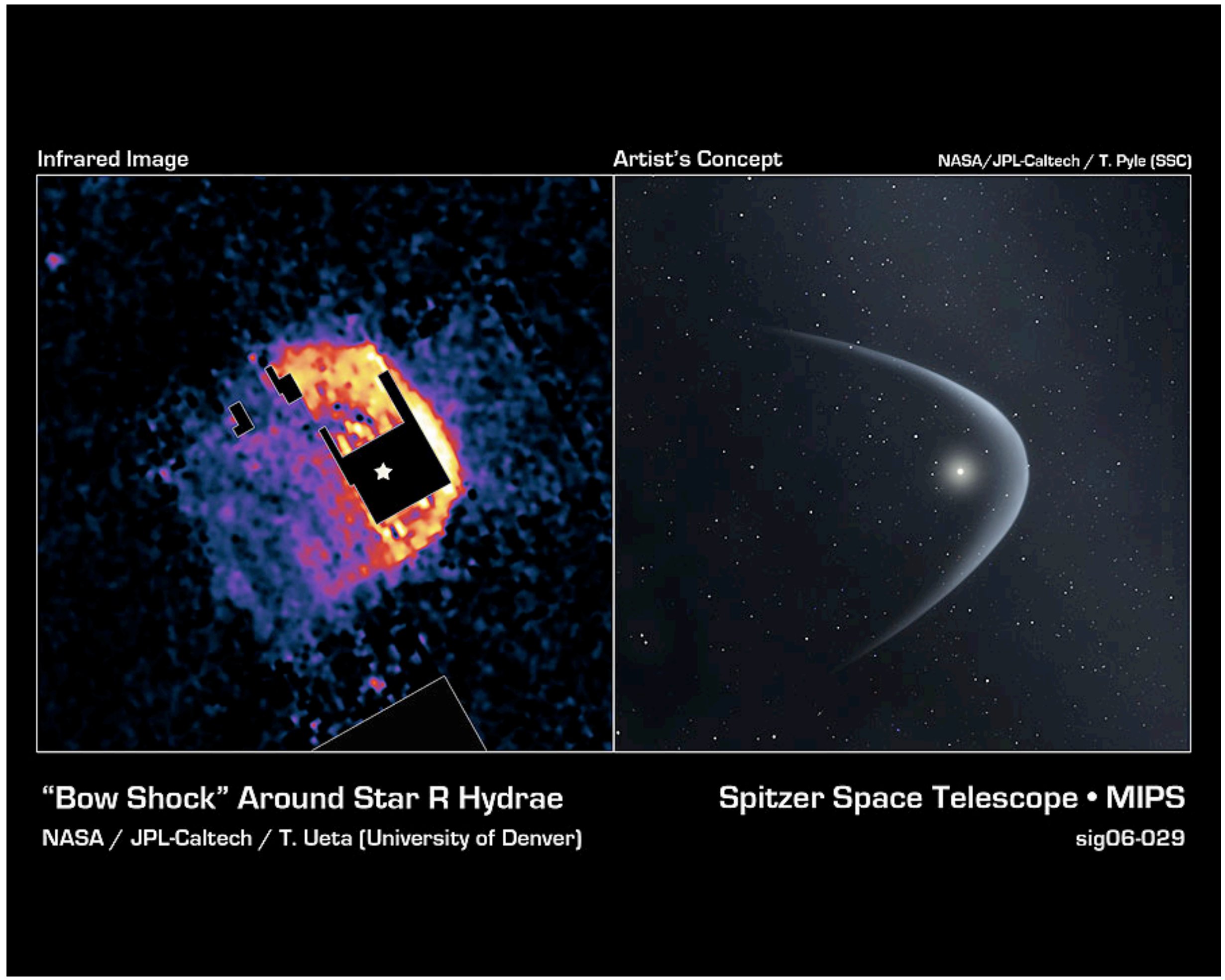


FIG. 15.—Snapshot taken from one of the 2D numerical experiments simulating the generation of a DF. The logarithm of the temperature, T_g, is shown, set to saturate at $\log T_g = 4.5$; the minimum temperature is roughly 2000 K ($\log T_g = 3.3$). The vertical scale has its origin at the height where $\tau_{500} = 1$. Contours of plasma β are drawn in white where $\beta = 0.1$, 1, and 10, with the $\beta = 1$ contour thicker for clarity. In black are drawn magnetic field lines covering the region where DFs ascend as a result of upwardly propagating shock waves. We find events that resemble observed DFs in this region, as well as in the corresponding opposite polarity region centered on $x = 12$ Mm. Note the highly intermittent nature of the chromospheric temperature structure and the ubiquity of shocks outlined by regions of high T_g. These shock waves seem to preferentially enter the corona where the magnetic field lines also enter the corona. The position of the transition region does not change much in the regions between $x = 5$ and 12 Mm, where the field is more horizontal. [*This figure is available as an mpeg animation in the electronic edition of the Journal.*]

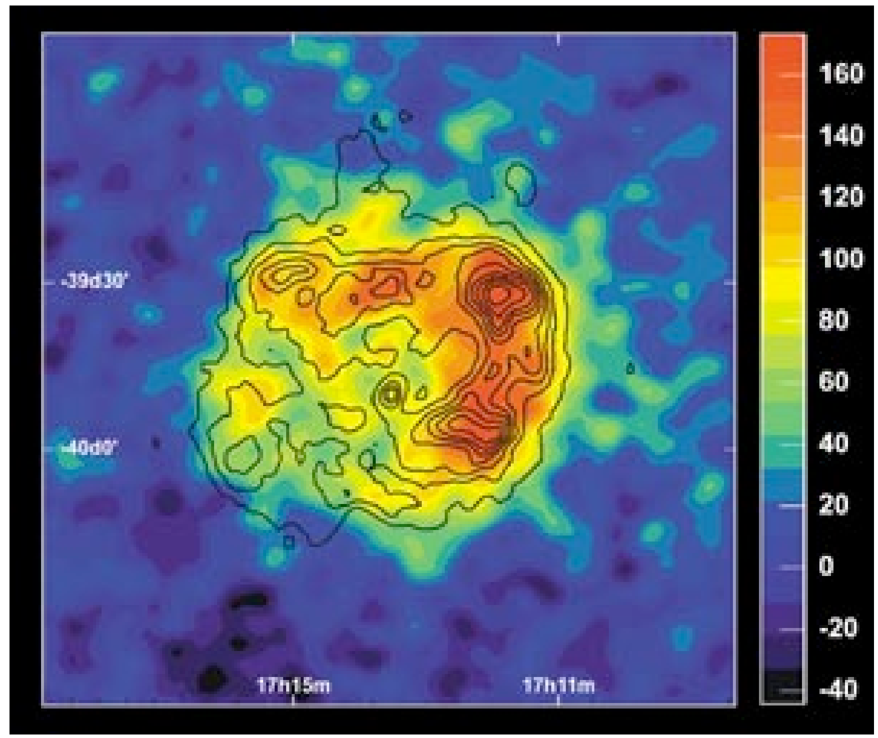
Going Further …

For helio(?)-spheric boundaries



Going Further …

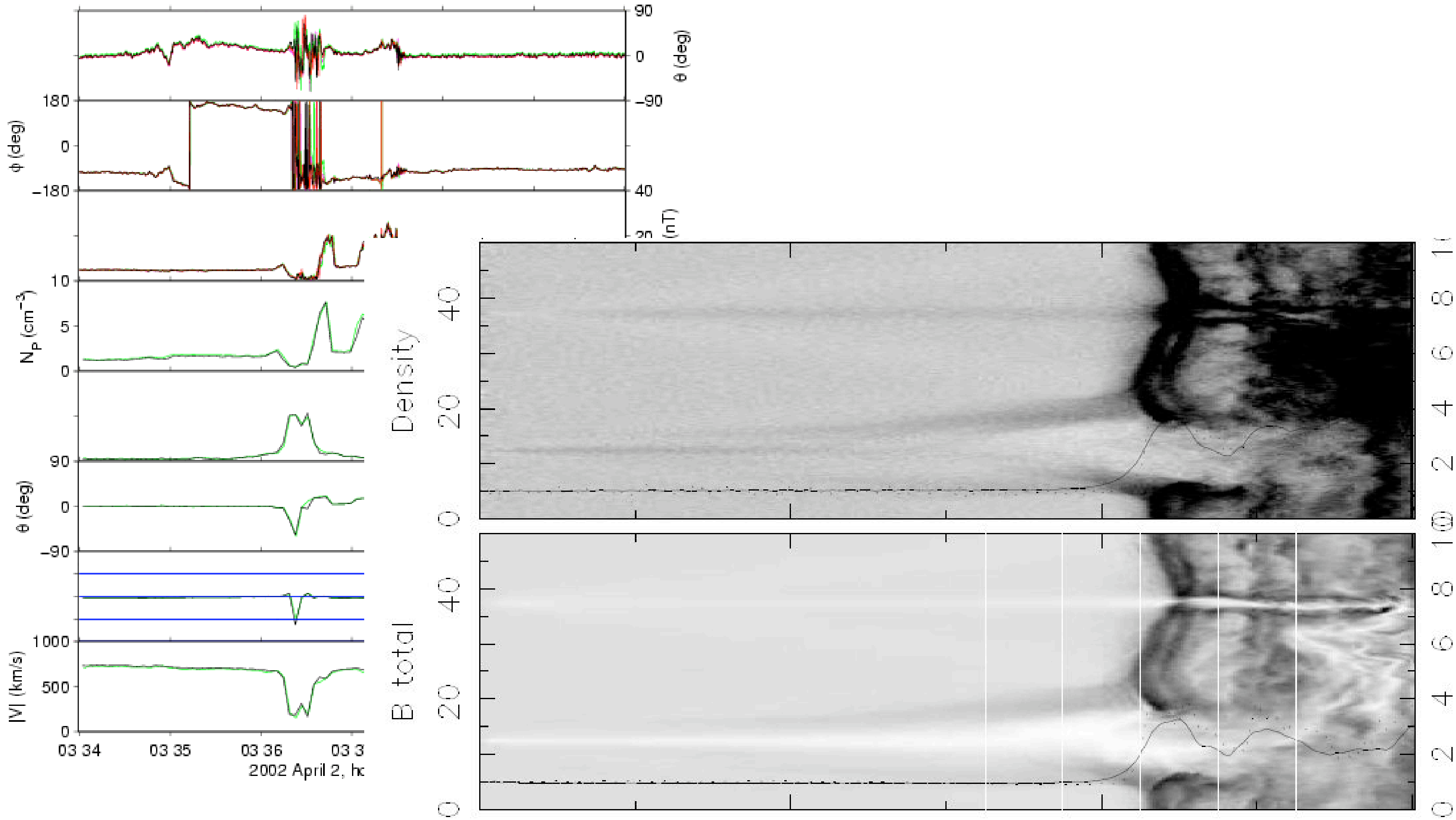
For particle acceleration



Hot Flow Anomalies

- Discovered at Earth's bow shock
- Structure/event with hot isotropic plasma and strongly deflected flow
- Associated with collision of discontinuity with (q-perp) bow shock
- A possible source of upstream energetic particles (ahead of q-perp shock)?

Observations and Simulations



Hot Flow Anomalies and the Termination Shock

- Scale lengths at termination shock are much larger than at Earth's bow shock
- Could interaction of large scale discontinuities disrupt the termination shock?
- Or act as gateway for downstream energetic particles?
- The difficulties …