INTERPLANETARY SHOCK WAVES FROM McMATH
REGION 11976 DURING ITS PASSAGE IN AUGUST 1972

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Abstract (*J. Geophys. Res.*). The August 1972 events provided an excellent opportunity for synthesizing a variety of observations in a coordinated fashion for the purpose of improving flare-shock associations, and our understanding of interplanetary shock propagation and solar wind interaction with planets and comets. These observations included the usual sudden commencements of magnetic storms at Earth; preliminary shock data from Heos-2, Prognoz-1 and Prognoz-2 (at Earth) and the radially-aligned Pioneers 9 (0.77 AU) and 10 (2.2 AU) located about 45° east of the
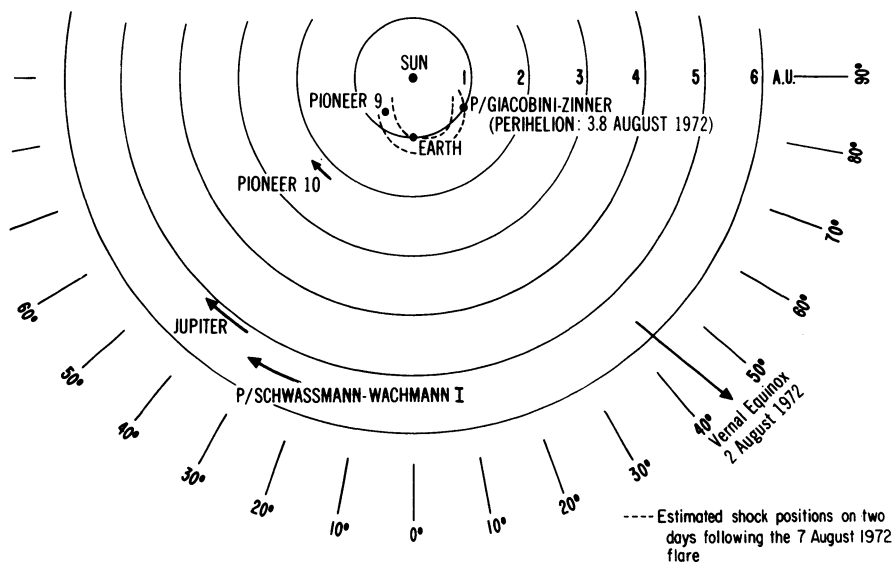
Fig. 1. Positions of Pioneers 9 and 10, Jupiter, and Comets *P*/Giacobini-Zinner and *P*/Schwassmann-Wachmann I relative to a fixed Sun–Earth axis during the epoch 1972 August 2–11.

Sun–Earth axis; solar radio types II and IV (as reported in World Data Center A's UAG Report 28, 1973, and this Symposium); discrete radio source scintillations in the solar wind; and the more speculative ideas regarding the solar wind's interaction with planets and comets. In the last case, Jupiter and Comet P/Schwassmann-Wachmann I exhibited non-Io-associated radio emission and a brightness increase, respectively, as a possible result of shock waves from the flare and/or coronal ejection activity initiated on 1972 June 15. During the August events, Comet P/Giacobini-Zinner exhibited statistically-significant sudden brightness decrease following its perihelion on 1972 August 4 at 1 AU approximately 57° west of the Sun–Earth axis.

Figure 1 shows the various 'stations' in space. Shocks at Pioneers 9 and 10 were identified by detailed analysis of plasma and magnetic field data. SSCs at Earth and
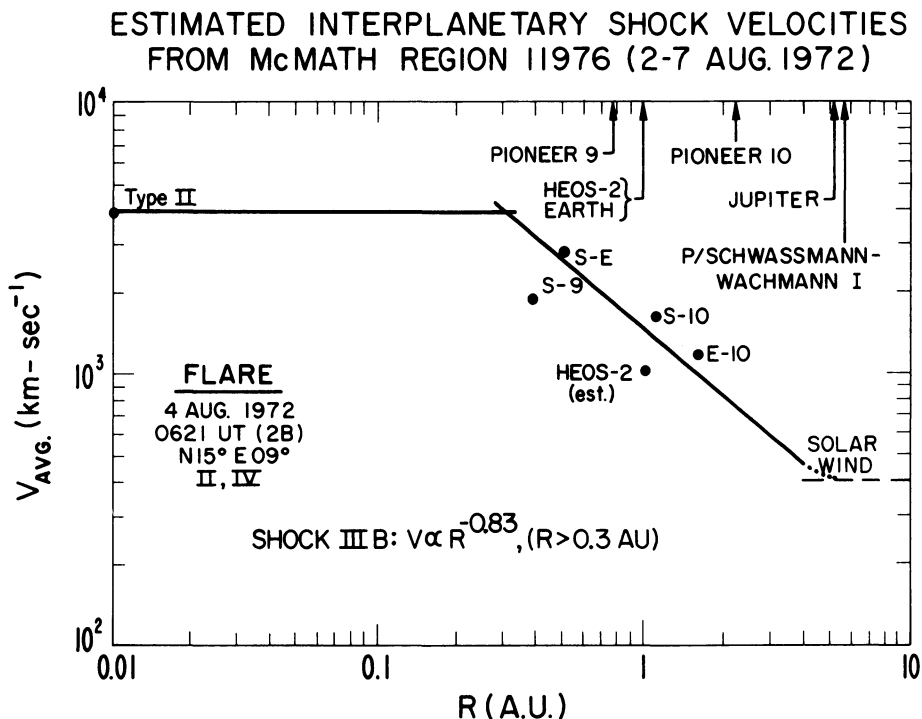

Fig. 2. Approximate shock trajectory from the flare on 1972 August 4 as inferred from the sudden commencement of a geomagnetic storm at Earth and *in situ* shock measurements observed at Pioneer 9 and Pioneer 10. The rapid deceleration suggests that (1) the energy input during the flare was impulsive thereby producing a 'blast' wave, or (2) the energy input produced a 'piston-driven' shock wave which decelerated rapidly after the cessation of the flare. The trajectory is 'approximate' in the sense that spherical symmetry is assumed. Thus, $V_{Avg} = R_i/(t_i - t_f)$, where R_i is the heliocentric radius to the measurement station, 'i'; t_i is the time of shock arrival at station, i; and t_f is the time of the flare noted on the figure. Possible non-spherical collimation of the flare's shock wave and/or large-scale deformation of the shock by ambient solar wind inhomogenities are neglected. The various points, such as S-E, S-9,… refer to the average shock velocities between the Sun and Earth, Sun and Pioneer 9, etc. In several cases, the points refer, for example, to the average velocities between Pioneer 9 and Pioneer 10. In this case, of course,
$$V_{Avg} = \Delta R/(t_{10} - t_9), \text{ etc.}$$

a brightness decrease of P/Giacobini-Zinner on 1972 August 9 or 10 (followed by an equally precipitous intensity increase in the visible) were also used as timing devices. There was no response at either Jupiter or P/Schwassmann-Wachmann I for reasons suggested on the basis of shock deceleration noted below.

The first interplanetary shock, denoted as Shock I, was ejected following the August 2 flare (14° N, 35° E, optical 1B, types II and IV, 0316 UT maximum). Its deceleration was fairly fast with a power law index of -1.1 for its variation of average velocity as a function of heliocentric distance. We have speculated that it was deviated from a collision course with Jupiter and P/Schwassmann-Wachmann I by deceleration into an Alfvén wave.

Shock II originated in the flare at 1958 UT on August 2 (13° N, 28° E, optical 2B, types II and IV radio bursts). It, too, decelerated rapidly following a piston-driven effect from the Sun to ~ 0.3 AU.

The third interplanetary shock (Shock III) was produced by the August 4 flare (15° N, 09° E, optical 3B, types II and IV, 0621 UT maximum). Its strong deceleration has a power index of -0.8 and is shown in Figure 2. A high initial velocity is implied
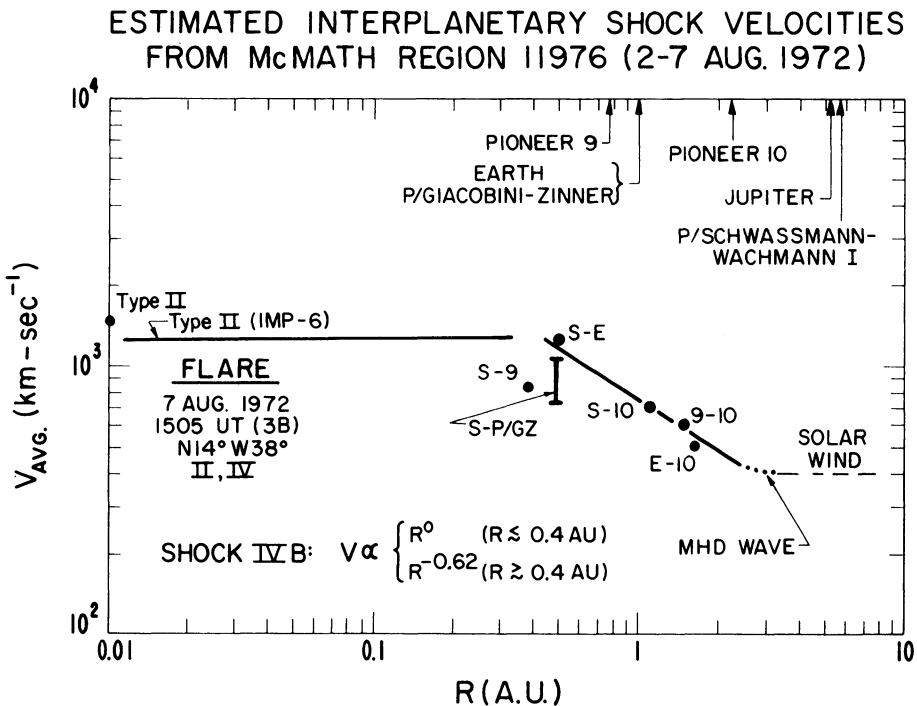

Fig. 3. Approximate shock trajectory from the flare on 1972 August 7 as inferred from the sudden commencement of a geomagnetic storm at Earth, low-frequency type II radio drifts observed by IMP 6, *in situ* shock measurements observed at Pioneers 9 and 10, and brightness diminution of Comet P/Giacobini-Zinner. The piston-driven character of the shock wave with fairly rapid deceleration beyond 0.5 to 1.0 AU is likely for this case. Note that shock wave decay to an MHD wave is indicated prior to 5 AU if the ambient solar wind velocity is assumed to be ~ 400 km s^{-1}.

at the Sun. More significantly, it appears to have decayed to a harmless Alfvén wave before reaching 5 AU in a blast-wave fashion, following a similar piston motion.

Shock IV was produced by the August 7 flare (14°N, 38°W, optical 3B, types II and IV, 1516 UT maximum) which probably produced a visual brightness decrease of P/Giacobini-Zinner. We believe that this is possible when the usual solar wind flux of $\sim 10^8$ cm^{-2} s^{-1} is impulsively increased behind the shock (near the piston) to $\sim 10^9$ cm^{-2} s^{-1}. Lifetime against impact dissociation for C_2 (for example) is thereby decreased to about three days which is competitive with photodissociative processes. Figure 3 shows that the shock velocity was initially fairly constant (implying continuous energy outflow at the Sun) with a more blast-like deceleration thereafter. Again, this shock also appears to have decayed prior to reaching the 5 AU position.

Detailed studies of these events will hopefully contribute to improved theories of interplanetary shock origin and propagation as well as solar wind interaction with cometary atmospheres. We do not wish to imply that the shocks noted above were the only ones produced by this spectacular display of flares. Additional shocks may indeed have been produced, and shock-shock interactions could have occurred in interplanetary space. Pending detailed analysis of all spacecraft data, including the various plasma and magnetic fluxes within the transient shock ensembles, we suggest that the shocks noted above are the essential discontinuities during the passage of McMath Region No. 11976 on the visible disk during 1972 August. Such analysis will also, hopefully, assist in the correlation of interplanetary events and the solar disturbances responsible for their existence.

DISCUSSION

Brandt: I would give the comet data very low weight in your study. F. D. Miller and B. Donn and J. Rahe have studied comet heads hit by interplanetary shocks and find no discernible effect on the comet. Hence, changes in cometary brightness or form may not be produced by shocks.

Dryer: We were looking for all possible effects of the shock. Scintillation data suggest that there were effects near the comet. The studies you cited were based upon a paucity of solar wind data.

Brandt: But comet workers searched for such effects and the evidence is negative.

Maxwell: I believe that 10^4 km s^{-1} velocity deduced from the radio data by Dodge was based on a mis-identification. We observed two components – one at 1000 km s^{-1} and one at 3000 km s^{-1}.

Riddle (to Maxwell): The identification of the disturbance stated by Dodge to be a type II burst with a

velocity of 9000 km s^{-1} is indeed in doubt. However, from the Boulder records there is no doubt that a disturbance with velocity 9000 km s^{-1} did exist, whatever its spectral type, as deduced by irregularities in the fringe lines on the interferometer record of a preexisting burst.

Sakurai: I would like to ask you what is the source of the piston which you say maintains the velocity before the deceleration? Is this related to the propagation of a moving type IV source in the solar atmosphere?

Dryer: I would like to give an affirmative answer, but no evidence exists between the observation at the sun and the still-sketchy plasma and field data observed by spacecraft. Regarding the latter, we have been speculating that anomalously-high alpha/proton abundance in the solar wind behind shocks (~ 0.15, compared with the usual 0.04) is the tracer for the plasma piston or ejecta from the flare. We need additional information provided by theory to help us identify these pistons. The piston's velocity (as presently 'identified' as just noted) is about 80% of the shock velocity which preceded it by some 5 h or so. We would like to 'connect' these observations to the type IV moving source. As spacecraft get closer to the Sun we will get more information on this question.