

AN EXAMINATION OF POSSIBLE SOLAR WIND SOURCES FOR A
SUDDEN BRIGHTENING OF COMET IRAS-ARAKI-ALCOCK

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Abstract. Possible solar wind sources for a sudden global brightening of Comet IRAS-Araki-Alcock are examined. No increases in solar wind momentum flux, solar energetic particles or solar activity occurred coincident with these brightenings. The only change in the solar wind coincident with the brightenings was a rotation of the interplanetary magnetic field to a more flow-aligned state. If this rotation did not lead to the cometary brightening, the brightening must have been intrinsic to the comet.

Introduction

It has long been known that cometary flaring events correlate with solar activity (Richter, 1954) and interplanetary shock waves and their accompanying momentum flux increases have long been proposed to be the cause (cf. Eviatar et al., 1970). However, until the present day we did not have the necessary solar wind data with which to check this hypothesis and even now seldom are solar wind measurements available near a flaring comet. However, Comet IRAS-Araki-Alcock presents us with such an opportunity. Initially discovered on April 26, 1983 by the Infrared Astronomy Satellite (IRAS) satellite, comet IRAS-Araki-Alcock (1983d) passed within 0.032 AU of the earth on May 11, 1983, the closest known approach of a comet in over 200 years. The visible coma extended over 10^5 km from the nucleus, subtending an angle of over 3° as seen from the earth (cf. Lutz and Wagner, 1986). During this period of time IRAS-Araki-Alcock (I-A-A) was observed intensively by a large number of observers. One of these studies produced an unprecedented documentation of a rapid and intense brightening of I-A-A (Lutz and Wagner, 1986). This flare-like event resulted in substantial increases in the flux from both the dust continuum and the gaseous emission bands in a matter of 20 minutes or less.

Lutz and Wagner (1986) considered two possible causes of this brightening. The first was that the brightening was triggered by an outburst of rocky ices from the nucleus. In this mechanism, as the ejected rock-ice particles travelled outward, the ices sublimated, releasing dust and gas which then was dissociated by the solar radiation. It is difficult to reconcile the observed velocities,

and the expected production rates of the observed emissions from C_3 , with the rate of brightening and the simultaneity of the brightening across the width of the inner coma. The second possibility that Lutz and Wagner considered was that a compression wave in the solar wind enhanced the gas and dust density of the coma. A rapid compression of the gas and dust would explain many of their observations. However, in their paper they do not establish whether such a density wave was in fact present in the solar wind at this time. Since I-A-A was relatively close to the earth, it is possible to examine terrestrial and near-earth measurements to determine whether there was a change in the state of the solar wind at or near the time of the I-A-A brightening. It is the purpose of this note to examine those data.

Solar Wind Observations

Figure 1 shows the magnetic field observed by IMP-8 on May 10, 1986. IMP 8 was $26 R_e$ in front of the earth, $17 R_e$ to the afternoon side and $15 R_e$ above the ecliptic plane at this time. At noon on May 10 I-A-A was $53 R_e$ in front of the earth, $423 R_e$ to the afternoon side of the earth and $844 R_e$ above the ecliptic plane. There are three "events" in the solar wind on this date that might be expected to be able to influence a cometary brightening. There is a period of nearly radial field starting close to 0800 UT, a directional discontinuity in the field at 1740 UT and an interplanetary shock at 1849 UT. We will discuss each of these intervals in turn. Figure 2 shows plasma data measured by the Los Alamos solar wind detector and the University of Chicago energetic ion fluxes measured by IMP-8 during this period. The two major features in these data are jumps in density and energetic ion flux at a directional discontinuity at 1740 UT and similar changes across an interplanetary shock at 1850.

The Radial Interplanetary Magnetic Field Interval

In order to determine whether a structure in the solar wind as seen at IMP-8 could have caused the brightening phenomena at I-A-A, we must calculate the possible time delay from I-A-A to IMP-8. The corotation delay from I-A-A to IMP-8 for structures perpendicular to the ecliptic plane (i.e., with normals in the ecliptic plane) and lying along the Parker spiral was 1.65 hours. Any such structure would have reached IMP-8 about 1.65 hours after reaching I-A-A, i.e., about 0800 UT. As shown in Figure 3 there

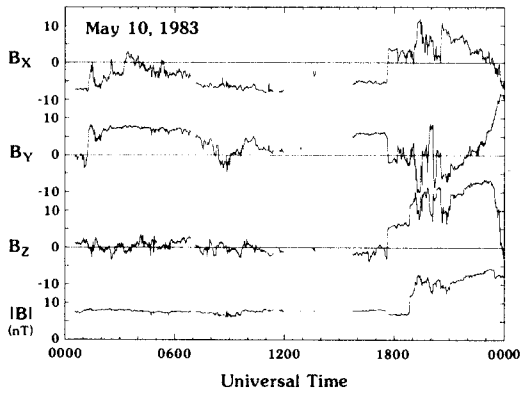


Fig. 1. One minute averages of the magnetic field in solar ecliptic coordinates obtained by IMP-8 May 10, 1983.

was a directional change in the IMF at this time. At 0700 UT the IMF lay at a rather large angle to the solar wind flow, 60° , but by 0800 UT it had changed to about 30° and by 0930 UT had reached an angle of less than 10° to the flow. The solar wind at IMP-8 at this time had a proton number density of about 2 cm^{-3} and was flowing at 440 km/sec as shown in Figure 2. Since the orientation of the IMF relative to the solar wind velocity vector controls the strength of the electric field in the solar wind, we might expect this change to affect the solar wind interaction with the comet. We defer any discussion of how this might relate to the observed brightening to a later section of this paper.

It is difficult to determine precisely the time delay from I-A-A to IMP-8 because it depends strongly on the orientation of the structure and it is difficult to determine the orientation of the discontinuity responsible for the IMF changes around 0800 UT because there is no clearly defined boundary of the field variation. If the normal to the surface of the structure was not nearly in the ecliptic plane, the time delay could be quite different from 1.65 hours because of the great distance of I-A-A above the ecliptic plane. I-A-A did not cross the ecliptic plane until two days later, early on May 12.

The Directional Discontinuity of 1740 UT

As shown in Figure 1 there was a large change in the orientation of the IMF and a slight drop in field strength at 1740 UT. The solar wind number density and velocity before the current sheet crossing were 2.1 cm^{-3} and 420 km/s respectively. After the current sheet passage they were 6.4 cm^{-3} and 440 km/sec. Thus the number flux increased from $8.8 \times 10^7 \text{ cm}^{-2} \text{ sec}^{-1}$ to $2.8 \times 10^8 \text{ cm}^{-2} \text{ sec}^{-1}$ or an increase by a factor of 3.2. The dynamic pressure or momentum flux increased a factor of 3.3. This change would have been sudden as required by the observations of Lutz and Wagner (1986). Furthermore, there was a strong increase in $E \geq 1 \text{ MeV}$ protons across the discontinuity as measured by the IMP-8 energetic particle telescope as shown in Figure 2. Thus, if the orientation of this boundary were appropriate for the required time delay, this boundary crossing would be an ideal candidate to cause the observed brightening.

In order to determine the orientation of the boundary we must analyze the change in field through the boundary. The change in field orientation occurred via a well-defined rotation of the magnetic field whose normal was $(-0.74, -0.61, 0.28)$ in solar ecliptic coordinates. There was no normal component of the IMF across the discontinuity within the accuracy of the minimum variance determination. The surface lay along the Parker spiral direction i.e., the normal was orthogonal to the Parker spiral and it tilted in such a direction as to decrease the delay from I-A-A to IMP-8 to about 10 minutes. The normal to the discontinuity would have to have been pointed downward at a significant angle to the ecliptic plane in order to cause a significant delay between an event at I-A-A and one at IMP-8. However, the orientation of this normal is well determined with a ratio of eigenvalues of 34 to 1 to 0.05. Thus it is difficult to suppose that this boundary crossed I-A-A at 0630 UT as required to explain the brightening.

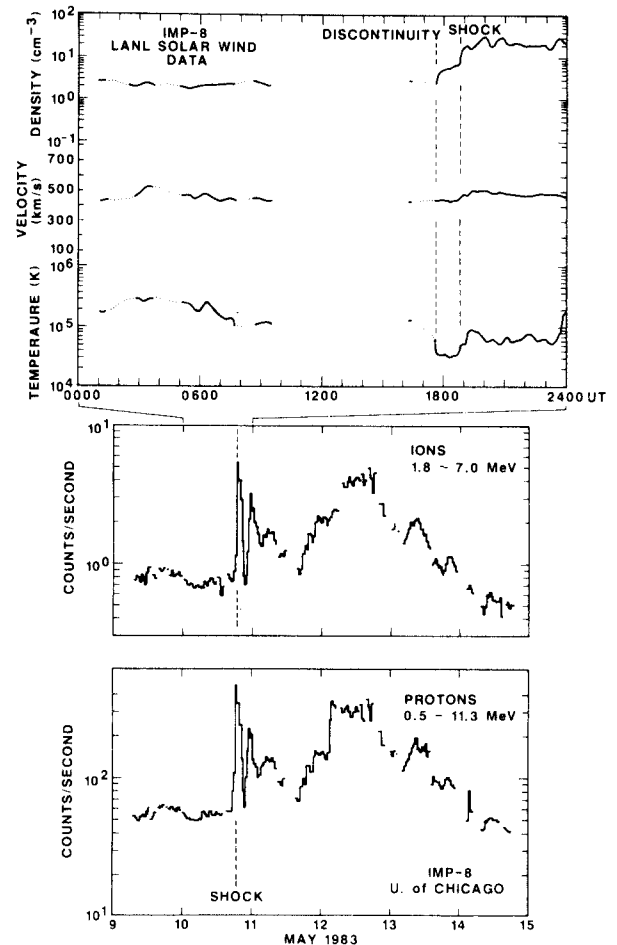


Fig. 2. Solar wind plasma and energetic ion data measured by IMP-8 surrounding the brightening of the coma of I-A-A on May 10, 1983. Top panel shows the ion temperature, density and velocity measured by the Los Alamos Solar Wind analyzer (S. J. Bame, personal communication, 1986) for the period corresponding to Figure 1. The bottom panel shows 5 days of energetic ion data measured by the University of Chicago detector (J. A. Simpson, personal communication, 1986).

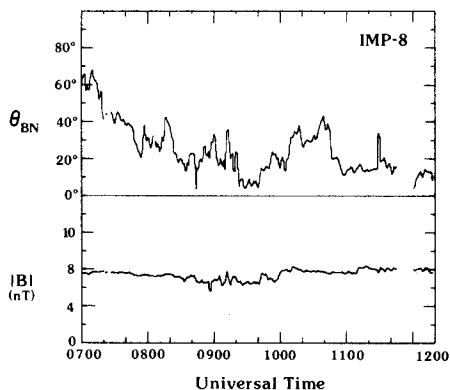


Fig. 3. Cone angle and magnitude of interplanetary magnetic field during the period of near radial alignment on May 10, 1983. The cone angle measures the angle between the IMF and the anti-solar direction and is zero for fields directly away from the sun.

The Interplanetary Shock of 1850 UT

The shock front which crossed IMP-8 at 1850 UT would also have provided a sudden increase in number and momentum flux. Prior to the shock encounter the solar wind density and velocity were 9.2 cm^{-3} and 430 km/sec respectively. After it, they were 19 cm^{-3} and 470 km/sec , resulting in a number flux increase of a factor of 2.3 and a momentum flux increase of 2.5. The calculation of the shock normal is somewhat more difficult than the calculation of the current sheet normal. If we use magnetic coplanarity (cf. Abraham-Shrauner and Yun, 1976), we obtain a normal of $(-0.59, +.79, -.16)$ which would result in a delay of only slightly over one hour between I-A-A and IMP-8. If we use in addition the change in velocity across the shock as determined by the MIT plasma detector (A. J. Lazarus, personal communication, 1986), the normal changes so as to be more nearly parallel to the normal of the earlier tangential discontinuity and thus in the direction of even shorter delays. It appears that the interplanetary shock could not have been responsible for the brightening either.

Solar Observations

If a solar wind momentum flux increase did not cause the observed brightening, and if an external, non-cometary, trigger of the brightening is suspected, then a direct solar source is a possibility, i.e., a transient increase in the photon flux from the sun in some spectral band to which the comet is sensitive. Thus, we examined solar records in the Solar Geophysical Data Prompt and Comprehensive Reports. We examined data on sudden ionospheric disturbances to look for evidence of enhanced EUV flux but there were none reported on May 10, 1983 from 0500-1000 UT. We checked for possible solar flare associated effects but there were no significant solar flares from 0550 to 0650 UT. To check for the possibility of a powerful but hidden flare, radio data were examined, but there were no radio events from 0500-1200 UT on 10 May. Finally, we examined the GEOS X-ray data and found, in agreement with all the above

evidence, that the 0630 UT brightening at I-A-A occurred during a very quiet solar period.

Discussions and Conclusions

There seems to be no obvious solar wind plasma or solar-related electromagnetic or energetic particle cause of the sudden brightening of comet IRAS-Araki-Alcock on May 10, 1983. Unless there is a very large reorientation of the surface of the directional discontinuity at 1740 UT or the shock at 1849 UT, it is very unlikely that an increase of solar wind momentum flux caused the brightening. It is also very unlikely that any increase in EUV or X ray flux from the sun caused the brightening. Either the brightening was intrinsic to the comet contrary to the conclusion of Lutz and Wagner (1986) or the brightening was caused by the radial alignment of the IMF.

The alignment of the magnetic field with the solar wind flow could affect the interaction of the solar wind with a comet. The comet-like pick-up of ions at Venus seems to be clearly affected by this alignment (Alexander et al., 1986). When the magnetic field is perpendicular to the solar wind flow, a well-developed magnetic barrier is formed as the ions from the neutral atmosphere of Venus are picked up by the solar wind flow and slow the flow. When the IMF is parallel to the solar wind flow, the pick up is not as effective and the mass-loading process is not as effective at creating a barrier to the solar wind flow. It is possible that this occurred at IRAS-Araki-Alcock on May 10, 1983 also. We suppose that under conditions of usual IMF orientation (when the IMF had a significant component perpendicular to the solar wind flow), the inner regions of the coma were effectively shielded from the solar wind flux and the majority of the ionization and excitation in the coma was caused by photons. The boundary at which the plasma becomes

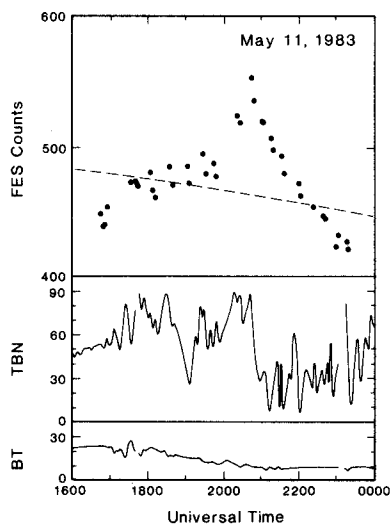


Fig. 4. Upper panel shows flux in $\sim 18''$ square aperture as measured by the IUE Fine Error Sensor. The dashed line shows the expected behavior of the cometary continuum (after Feldman et al., 1984). The lower two panels show the cone angle of the IMF, labelled TBN, and the IMF magnitude as measured by IMP-8.

predominantly cometary in origin has been termed the cometopause by Gringauz et al. (1986). The region inside the cometopause should be considered to be the cometary magnetosphere.

When the IMF turned radial and became aligned with the solar wind flow, the coma may no longer have been shielded from the solar wind flux and electron impact ionization and excitation became important, because the cometopause and the cometary magnetosphere diminished in size. In fact, Cravens et al. (1987) have recently calculated that in the cometary magnetosheath within 10^4 km of the nucleus of Halley, the ionization rate due to solar wind electron impact is several times that of the photoionization rate. The amount of ionization relative to dissociation of the neutral gas depends on the energy spectrum of the solar wind electrons. If no shock were to form as might be expected for a radial IMF, then the solar wind electrons would have a temperature of about 10 eV and certainly would cool further once they reached the region of significant Coulomb collisions with the cometary electrons. Thus it is possible that there would be little ionization. The cause of the brightening of the continuum must be more speculative, since it involves reflection from the dust particles and we do not understand completely the interaction of the solar wind and the dust population of a comet. One effect that should occur is that the charge state of the dust should go from positive to negative when the solar wind encountered the dust. If the dust became sufficiently charged to break up this could increase the scattered light. It is very difficult to test these hypotheses without in-situ data. All we can say is that it is conceivable that the I-A-A brightening simply reflects the destruction or weakening of a previously existing magnetic barrier together with the slower transport of the newly created plasma. While such a hypothesis is difficult to check remotely because of the low correlation length of the IMF (cf. Russell et al., 1980), it would be simple to check with a rendezvous mission to a comet.

One other brightening of I-A-A was reported by Feldman et al. (1984) and A'Hearn and Feldman (1985) as seen by the IUE spacecraft at both ultraviolet and visible wavelengths. This brightening was not as precisely timed or well documented as the May 10 outburst. As shown in Figure 4 it was seen beginning about 2000 UT on May 11 or possibly somewhat before this time. It was ascribed to a variation in the outgassing rate (Feldman et al., 1984) or possibly the momentum flux of the solar wind (A'Hearn and Feldman, 1985). The solar wind velocity was increasing at the time of the outburst. We note, however, that there was a very large change in the IMF orientation as seen by IMP-8 at 2045 UT. Assuming the nominal corotation delay of a little over 2 hours at this time, the cone angle change would have been felt at I-A-A about 1830 UT. The IMF cone angle changed from 85° to close to 20° in about 15 minutes, and the brightening appears to have begun about this time. This association raises the possibility that this second brightening was also triggered by a

change in the access of the solar wind to the inner coma.

In summary, it is unlikely that the sudden global brightening of comet IRAS-Araki-Alcock on May 10, 1983 was due to an increase in the momentum flux of the solar wind as proposed by Lutz and Wagner (1986). If their hypothesis is correct that the brightening of the comet was not due to some internal cometary process, then it is most likely that the brightening was caused by the radial alignment of the IMF which was seen at IMP-8 after about 0800 UT.

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References

- Abraham-Shrauner, B. and S. H. Yun, Interplanetary shocks seen by Ames plasma probe on Pioneer 6 and 7, *J. Geophys. Res.*, **81**, 2097-2102, 1976.
- A'Hearn, M. F. and P. D. Feldman, S_2 : A clue to the origin of cometary ice?, in *Ices in the Solar System*, (edited by J. Klinger et al.), 463-471, D. Reidel Publ. Co., Dordrecht, Netherlands, 1985.
- Alexander, C. J., J. G. Luhmann and C. T. Russell, Interplanetary field control of the location of the Venus bow shock: Evidence for comet-like ion pickup, *Geophys. Res. Lett.*, **13**, 917-920, 1986.
- Cravens, T. E., J. U. Kozyra, A. F. Nagy, T. I. Gombosi and M. Kurtz, Electron impact ionization in the vicinity of comets, *J. Geophys. Res.*, **92**, 7341-7353, 1987.
- Crooker, N. U., G. L. Siscoe, C. T. Russell and E. J. Smith, Factors controlling degree of correlation between ISEE-1 and ISEE-3 interplanetary magnetic field measurements, *J. Geophys. Res.*, **87**, 2224-2230, 1982.
- Eviatar, A., J. M. Joseph and M. Dryer, A proposed mechanism for comet flares, *Astrophys. Lett.*, **7** 27-29, 1970.
- Feldman, P. D., M. F. A'Hearn and R. L. Millis, Temporal and spatial behavior of the ultraviolet emissions of comet IRAS-Araki-Alcock, *Astrophys. J.*, **282**, 799-802, 1984.
- Gringauz, K. I. et al., First in-situ plasma and neutral gas measurements at comet Halley, *Nature*, **321**, 282-285, 1986.
- Lutz, B. L. and R. M. Wagner, Temporal variability of comet IRAS-Araki-Alcock (1983d): The May 10 Event, *Astrophys. J.*, **993**-1000, 1986.
- Richter, N. B., *Statistik und Physik der Kometen*, Barth, Leipzig, 1954.
- Russell, C. T., G. L. Siscoe and E. J. Smith, Comparison of ISEE-1 and -3 interplanetary magnetic field observations, *Geophys. Res. Lett.*, **7**, 381-384, 1980.

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