Reports

Interplanetary Magnetic Field Enhancements and Their Association with the Asteroid 2201 Oljato

Abstract. *Comparison of the times of occurrence of a newly discovered type of disturbance in the interplanetary magnetic field at 0.72 astronomical unit with the passage of the small Venus-crossing asteroid, 2201 Oljato, reveals a possible association, but the source of these disturbances appears to be associated with outgassing material in the Oljato orbit some distance behind the asteroid and not with the asteroid itself. This suggested association can account for one quarter of the total number of events seen in eight Venus years.*

Examination of Pioneer Venus observations of the interplanetary magnetic field at 0.72 AU has revealed a new class of magnetic variation, in which the magnetic field increases to a peak and then decreases almost symmetrically. The largest of these events lasted almost 10 hours and rose to a peak field strength over 140 percent of that of the surrounding magnetic field. It was suggested that this enhancement of the magnetic field was associated with the passage of a comet by Venus (*1*). An examination of the first five terrestrial years of Pioneer Venus interplanetary magnetic field data has now been completed, and 31 similar but smaller events have been catalogued (*2*). The location of these events bears no relation to the relative position of the spacecraft and Venus but does bear some relation to the location of Venus in ecliptic longitude. These events occur randomly with respect to solar wind stream structure and have no obvious relation to interplanetary shocks. The fact that these locations group into families of events at specific ecliptic longitudes has been used as the basis for suggesting that these events are associated with small Venus-crossing bodies. Thus we instituted a search for close approaches to Venus of cometary and asteroidal bodies, using the frequently updated standard Jet Propulsion Laboratory minor planet ephemeris file, which includes 3530 numbered and unnumbered asteroids and 100 short-period comets.

Because of its close approach to Venus, we examined the possible association of the Pioneer Venus events with the asteroid 2201 Oljato. The results of this investigation were surprising to us. Oljato appears to be associated with about one quarter of the total number of events.

Oljato orbits the sun in an elliptical orbit with a period of 1770 days (5.21 Venus years) and with a slight (2.5°) inclination to the ecliptic plane. With an aphelion of 3.72 AU and a perihelion of 0.63 AU, it crosses the Venus orbit and lies within it at ecliptic longitudes from 126° to 219°. Not only does Oljato's orbit have a small inclination but also the orbit plane is oriented such that the ecliptic latitudes of the Oljato and Venus orbits differ by only from 0.5° to 0.9° when Oljato is inside the Venus orbit. Thus, when Oljato crosses the Venus orbit (inbound) it comes within 10^6 km of the Venus orbit, and outbound it comes within 1.3×10^6 km. Figure 1, a and b, shows the positions of Venus and Oljato in 1980 and 1983 at the times of Oljato's last periapsis passages. Also shown are the locations of the interplanetary field enhancements seen at Venus as it crossed this sector just after Oljato passed by. Only one other event was seen in each of the 360° of longitude surrounding these two perihelia, and each of these events was well removed from the Oljato sector.

Oljato was originally discovered in 1947 by H. L. Giclas at the Lowell Observatory and was designated 1947XC and 1979XA prior to the determination of reliable orbital parameters. Oljato was named in March 1983 for the place of Moonlight Water near Monument Valley, Utah, on the Navajo Indian Reservation (*3*). Oljato has an estimated diameter of about 1.4 km. Infrared observations reveal it to have a high albedo (40 to 50 percent) (*4*). It has unusual narrow-band ultraviolet reflectivities (*5*). Its absolute magnitude in blue light is 16.70 (*6*).

Even though Oljato may have promising orbital characteristics, it must also have the proper phasing in order to be responsible for the observed events. Oljato passes by Venus every 5.2 Venus years. Oljato crossed the Venus orbit inbound on 30 January 1980, 51 days before the arrival of Venus at that point, and crossed the Venus orbit outbound on 10 March, 69 days prior to Venus's arrival at that point (Fig. 1a). In 1983, Oljato passed much closer to Venus (Fig. 1b). On 14 April, it crossed the Venus orbit inbound only 5 days before Venus arrived at that point and crossed outbound

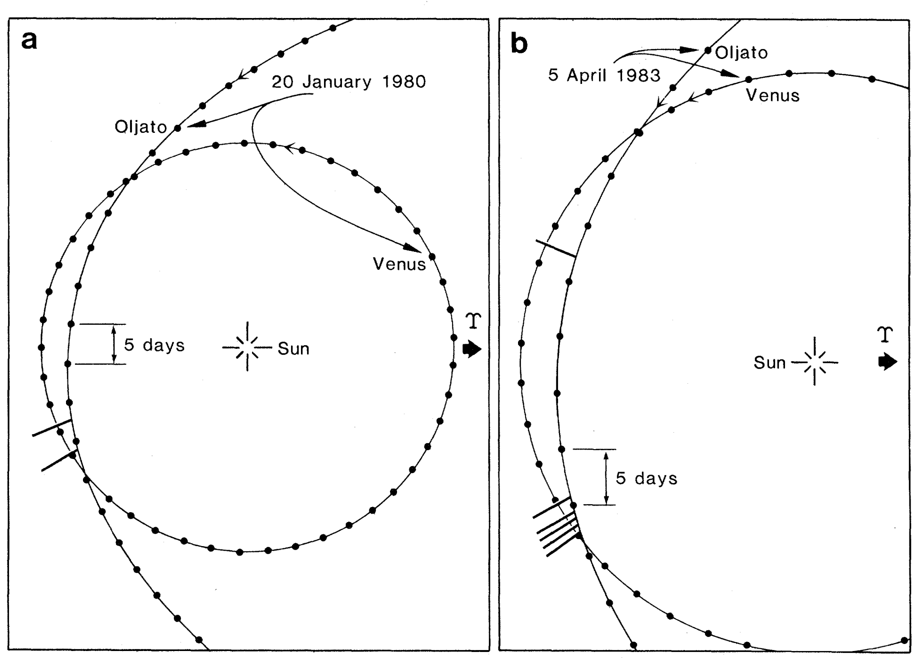


Fig. 1. Ecliptic-plane projection of the Venus and Oljato orbits: (a) the 1980 perihelion passage; (b) the 1983 perihelion passage. Positions are given every 5 days. Locations of interplanetary field enhancements are given by radial line segments extending from the Oljato orbit past the Venus orbit.

Table 1. Oljato-associated interplanetary field enhancements in 1980 and 1983.

Year	Month/ day	Duration (hours)	Width of field enhancement: Motion of Oljato ($\times 10^4$ km)	Width of field enhancement: Transverse solar wind velocity ($\times 10^4$ km)	Amplitude (%)	Venus: Longitude	Venus: Latitude	Oljato latitude	Oljato distance ($\times 10^6$ km)	Oljato delay (days)
1980	5/7.035	0.4	2.2	4.3	31	201.64°	2.77°	2.03°	8.6	66.4
	5/12.722	1.2	4.7	13	27	210.79°	2.42°	1.80°	4.5	68.0
1983	5/7.712	0.5	3.5	5.4	14	156.62°	3.35°	2.48°	12.5	9.5
	6/9.188	1.1	2.8	12	91	209.16°	2.48°	1.85°	5.5	20.9
	6/11.153	0.3	1.2	3.4	19	212.32°	2.35°	1.75°	3.9	21.4
	6/11.615	0.6	2.4	6.5	24	213.06°	2.33°	1.73°	3.5	21.5
	6/12.288	0.7	2.5	7.6	12	214.14°	2.28°	1.69°	2.9	21.6
	6/13.351	0.7	2.5	7.6	37	215.85°	2.20°	1.64°	2.0	21.9

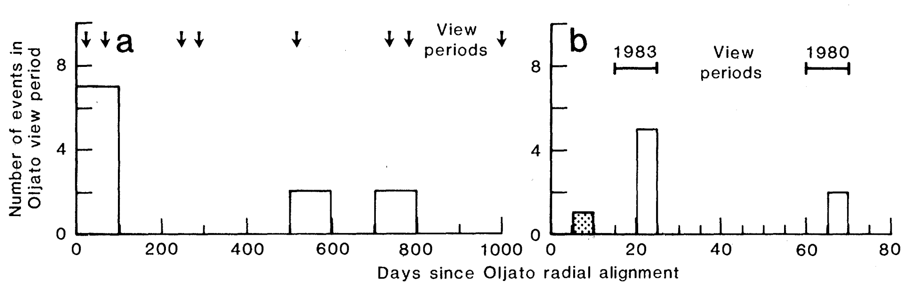
only 22 days before Venus's arrival. In neither case was Venus ever radially aligned with Oljato inside of Venus's orbit. Nor do the orbits appear to intersect, as seen from the sun, when the Oljato orbit is closer to the sun than the Venus orbit. Nevertheless, many events are seen in the sector of the Venus orbit in which Oljato passes inside of Venus, and they are much more frequent during the periods closest to the Oljato passage. Moreover, Oljato-related events, with one possible exception, occur after perihelion passage.

Figure 2a shows the number of events seen between the perihelion and the outbound intersection of the two orbits as a function of time since the last radial alignment of Oljato with that particular ecliptic longitude. Pioneer Venus has returned data from this region during eight different periods, as indicated by the arrows. During those periods 11 events have been detected. Since each Venus year we see an event on the average once every 70°, we would have expected to see about five events if these were solely random occurrences. There is clearly an excess in the number of events seen, and that excess occurs just after the passage of Oljato for seven of the 11 events.

Figure 2b expands Fig. 2a over the first 100 days since radial alignment. Five events occurred in 1983, about 21 days after Oljato went by, and two in 1980, about 67 days after its passage. One preperihelion event was observed in 1983 (shaded area). This event is one of the weakest.

The behavior of the events in Fig. 2b is consistent with the hypothesis that these events are associated with 2201 Oljato. There are more events when Oljato and Venus are closest in longitude. The chance that there will be two events randomly occurring in the postperihelion sector as there were in 1980 is 10 percent. The chance of five events as there were in 1983 is four parts in 10^4. Of the events seen in the postperihelion sector more than 100 days after radial alignment, only one occurred close to those of the 1980 and 1983 apparitions. Thus, we suspect that only the 1980 and 1983 events in this region are actually associated with material co-orbiting with Oljato.

It is also clear from the geometry that Oljato itself cannot cause the disturbances. Any bodies responsible for the observed disturbance must lag behind Oljato by up to 70 days but be in the same or similar orbit. Thus, we must be observing the interaction of the solar wind with material or debris lagging behind Oljato and this debris must be smaller in diameter than 1.5 km, or it would have been detected optically when the asteroid was observed in its near Earth passages. Small debris could interact with the solar wind by outgassing with subsequent photoionization and charge exchange of these released gases. This would slow down the solar wind (slightly if the outgassing rate is low) and cause the magnetic field to be compressed and distorted by the velocity shear thus induced. Only if the amount of mass added to the solar wind were large would a significant taillike field be expected to arise. Since none of these events show a strictly solar-pointing or antisolar field, either the mass loading is weak or the spacecraft has not penetrated to the center of the wake. We presume that the center of any magnetotail is approximately along the radial vector from the sun through the Oljato orbit and that Venus is probing the edge of the magnetotail. Thus, we calculate the minimum length of the magnetotail caused by the Oljato material as being the distance from the postulated Oljato debris to Venus projected along the sun-Oljato-debris line. This is displayed in Fig. 2c. The preperihelion event of 7



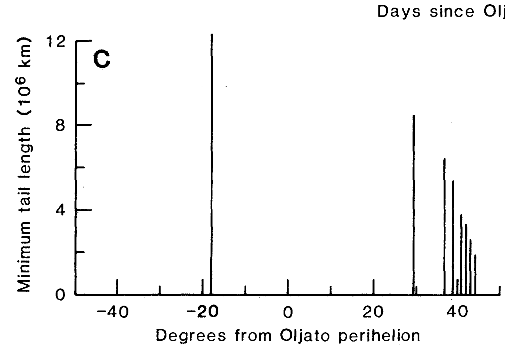


Fig. 2. Association of observed perihelion passages with interplanetary field enhancements seen at Venus. (a) Number of events in 100-day intervals since the last perihelion passage, that is, the number of days since Oljato was lined up with the observing longitude. (b) Number of events per 5-day intervals since Oljato passage. The one preperihelion event (shaded area) is indicated also. (c) The minimum tail length implied by these observations versus ecliptic longitude measured from Oljato perihelion. An Oljato view period is taken to be that interval when Venus is at those longitudes at which 2201 Oljato or material in the Oljato orbit would be between perihelion and the outbound crossing of the Oljato orbit.

May 1983 corresponds to a tail length of over 12×10^6 km, and the other lengths range from 2×10^6 to 8.5×10^6 km.

In order for Venus to be in the center of a magnetotail rooted in the Oljato orbit, the solar wind would have to flow at an angle to the ecliptic plane equal to at least 15° on the days on which events were detected. Deviations in the solar wind flow of up to 15° can occur but are extremely rare (*7*). Thus, we interpret our observations as occurring at the edge of a disturbed region, about 1.3×10^6 to 2×10^6 km from the center line of the sun-asteroid interactions. This gives us lower limits on two dimensions, the length of the tail and its width. In order to estimate its thickness, we use the duration of the field enhancement and assume a velocity. Using the relative velocities of Venus and Oljato across the Venus sun line, we obtain the values in column 3 of Table 1. Assuming that the wake is passing Venus at 30 km/sec (or 1 standard deviation of the flow velocity about the radial direction) (*7*), we obtain the thickness in column 4. This wide but thin field enhancement resembles the plasma density enhancement found in the recent magnetohydrodynamic simulation of a comet (*8*). At a distance of only 2×10^6 km behind the comet the simulated plasma disturbance is 0.15×10^6 km thick and 1.7×10^6 km wide. We expect the field disturbance that is rooted in this mass-loaded plasma to have similar dimensions.

For a wake cross section of 0.3×10^{12} km^2 in a solar wind flowing at 400 km/sec, 3×10^{29} solar protons per second are affected. However, when the wake has spread to this size, we see no perceptible perturbation in the velocity of the plasma. Assuming therefore that the velocity effect is thus less than 1 percent, we calculate that only the equivalent of 2×10^{26} oxygen ions per second are being added to the flow. This amounts to about 5 kg of gas per second. This process could occur for 10^5 years or longer for an Oljato-sized object [the expected dynamical lifetime for Apollo asteroids is a few tens of millions of years (*9*)].

The estimated outgassing for Oljato is much less than the outgassing rates associated with visible comets. For example, estimates of the mass loss of comet West at 0.4 AU are close to 2×10^{31} proton masses per second (*10, 11*). Comet-like properties for an Apollo asteroid are thus not totally unexpected. Apollo asteroids have been postulated to be extinct cometary nuclei because of the weakness of the asteroidal source in this region and because of their size (*12*). The comet Encke seems to be well on its way to becoming an Apollo asteroid (*13*). Oljato itself has been postulated on the basis of meteoric evidence to be a defunct comet (*14*) and even to be undergoing outgassing on the basis of ultraviolet reflectivities (*5*). We would like to encourage further ground-based observation of this interesting object to search for further signs of its activity.

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Lead-Iron Phosphate Glass: A Stable Storage Medium for High-Level Nuclear Waste

Abstract. *Results are presented which show that lead-iron phosphate glasses are a promising new waste form for the safe immobilization of both high-level defense and high-level commercial radioactive waste. Relative to the borosilicate nuclear waste glasses that are currently the "reference" waste form for the long-term disposal of nuclear waste, lead-iron phosphate glasses have several distinct advantages: (i) an aqueous corrosion rate that is about 1000 times lower, (ii) a processing temperature that is 100° to 250°C lower, and (iii) a much lower melt viscosity in the temperature range from 800° to 1000°C. Most significantly, the lead-iron phosphate waste form can be processed using a technology similar to that developed for borosilicate nuclear waste glasses.*

A new lead-iron phosphate glass nuclear waste form has been developed that appears to be unusually well suited to the safe immobilization and permanent disposal of various types of high-level radioactive waste. By melting lead-iron phosphate glass together with simulated nuclear waste, it is possible to form at a relatively low temperature a homogeneous stable glass in which the radioactive nuclei are chemically incorporated in the glass structure. The idea of creating a nuclear waste form by dissolving radioactive waste in a glass is, of course, not new; variations of this idea have been intensively investigated during the past 30 years. Most of this research, however, has focused on the use of different forms of borosilicate glass with compositions similar to Pyrex. Phosphate glasses were eliminated from serious consideration during the formative stages of nuclear waste host development. The lack of attention given to phosphate glasses as a nuclear waste form can be traced, in part, to an early study of a particular phosphate glass process developed at Brookhaven National Laboratory (*1*). The results of this study were not encouraging. Subsequently, with the exception of work carried out in West Germany during the development of the PAMELA process (*2*) (a waste disposal scheme in which alkali phosphate glass beads were incorporated in a metal matrix), research into essentially all phosphate glass waste forms was curtailed. In addition, the familiarity of researchers in the glass industry with the engineering and processing technology associated with the production of silicate or borosilicate glass has undoubtedly provided some impetus to the development of silicate-based nuclear waste forms.

Recent work on synthetic analogs of natural phosphate minerals such as monazite as possible storage media for high-