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THE ORIGIN OF THE WARPED HELIOSPHERIC CURRENT SHEET

by

J.M. Wilcox, P.H. Scherrer
and
J.T. Hoeksema

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Abstract

The warped heliospheric current sheet in early 1976 is calculated from the observed photospheric magnetic field using a potential field method. Comparisons with measurements of the interplanetary magnetic field polarity in early 1976 obtained at several locations in the heliosphere at Helios I, Helios II, Pioneer XI and Earth show a rather detailed agreement between the computed current sheet and the observations. It appears that the large-scale structure of the warped heliospheric current sheet is determined by the structure of the photospheric magnetic field, and that "ballerina skirt" effects may add small-scale ripples.

The existence of a warped current sheet in the non-polar regions of the heliosphere is now generally accepted (1-4). An artist's impression of an average shape of the current sheet at a time near sunspot minimum (2) is shown in Figure 1. As the current sheet rotates with the sun the sector structure of the interplanetary magnetic field (5) is produced. At the phase of the sunspot cycle discussed in this paper, the large-scale interplanetary magnetic field is directed away from the sun northward of the current sheet, and is directed toward the sun southward of the sheet. It should be noted that the term "interplanetary sector structure" coined by Wilcox and Ness (5) describes the structure in the plane of the ecliptic and does not refer to three-dimensional structures such as the sectors of an orange.

There are two points of view regarding the origin of the warped heliospheric current sheet. Svalgaard and Wilcox (6) review the computations of the magnetic field at a "source surface" using as a boundary condition the photospheric magnetic field observed using the Zeeman effect. Outside of the source surface the warped current sheet is assumed to be carried radially outward by the solar wind. In this model the structure of the current sheet (i.e. the location in solar longitude and the extent in solar latitude of the maxima and minima) is a direct consequence of the observed photospheric magnetic field.

Alfven (4; see also 7) has proposed an alternative viewpoint in which the solar origin of the current sheet is a plane similar to the plane (i.e. her waist) in which

the skirt of the ballerina originates. In this model the current sheet waves up and down like the skirt of a spinning ballerina.

It is the purpose of this note to show that the observations of the interplanetary magnetic field (IMF) during the first months of 1976 (i.e. near sunspot minimum) at Earth, by Pioneer XI near a heliospheric latitude of 16°N (8), and by Helios I and II between 0.28 and 1 A.U. within a latitudinal excursion $\pm 7.23^{\circ}$ from the solar equatorial plane (9) are in good agreement with a warped current sheet computed from the observed photospheric magnetic field by the methods reviewed in (6). It thus appears that the large-scale structure of the heliospheric current sheet is controlled by the photospheric magnetic field, although small-scale ripples may be added by dynamic solar wind processes (the ballerina effect).

The curved line in Figure 2 represents the average warped current sheet that separates regions with magnetic field away from the sun (above the line) and toward the sun (below the line), as computed on a source surface at 2.6 solar radii during the interval 20 January through 26 May 1976. The solar wind is assumed to carry the magnetic structure on the source surface radially outward into the heliosphere. In fact, the curved line in Figure 2 is rather similar to the bottom panel of Figure 4 in Svalgaard and Wilcox (6) which was computed as the average of eighteen 27-day solar rotations starting 5 May 1976 and ending 7 August 1977, i.e. just after the interval discussed in the present note. This similarity is evidence of the long-term stability of the large-scale photospheric and heliospheric magnetic fields.

Such long-term stability would not be expected from the dynamic effects of the ballerina skirt model. This stability would also not be expected if the predominant warps in the current sheet were caused by coronal holes (9) since the lifetime of a coronal hole is typically only several rotations. Since coronal holes appear in the central portion of sectors (6) it would be expected that

the longitudes of coronal holes would correspond to the longitudes of maximum warp of the heliospheric current sheet.

The dashed horizontal line in Figure 2 represents the heliographic latitude of 16°N near which Pioneer XI observed the interplanetary magnetic field to be predominantly away from the sun during the interval discussed in this note (8). The plus (away) and minus (toward) signs in Figure 2 represent the interplanetary magnetic field polarity as observed by Helios I and II (9) projected onto the solar corona. The computed current sheet in Figure 2 is similar to the inferred current sheet shown in Figure 4b of reference 9.

Figure 2 shows that the Helios spacecraft observations of the polarity of the interplanetary magnetic field are in good agreement with the computed location of the current sheet. Of particular interest is the detailed agreement in that when the Helios spacecraft were at southern heliographic latitudes they observed a two-sector pattern whereas when they were at northern latitudes they observed a four-sector pattern, just as is computed in Figure 2.

The curved line in Figure 2 representing the warped heliospheric current sheet is repeated in Figure 3, where the plus and minus signs show the inferred IMF polarity at Earth (10). A $4\frac{1}{2}$ day travel time from sun to Earth (11) is used in mapping this back to the corona. The IMF structure at Earth also shows a two-sector pattern when the Earth is near 7°S heliographic latitude, but hints of the four-sector structure are seen as Earth moves northward.

We note that if a $5\frac{1}{2}$ day travel time had been used, the data in Figure 3 would be moved to the right by about 13° longitude, which would significantly improve the agreement. The same situation exists with regard to the spacecraft data in Figure 2. This suggests that the simple mapping techniques used in preparing Figures 2 and 3 may be only an approximation.

While the large-scale structure of the current sheet persists for many solar rotations, on any particular rotation changes in the current sheet may occur due to the effects of solar activity and coronal holes (12). Nevertheless, the overall agreement in Figures 2 and 3 between the observed IMF polarities and the structure of the heliospheric current sheet as computed from the observed photospheric magnetic field is impressive.

Two predictions may be made from the considerations discussed in this note. First. If Pioneer XI had been at 16°S heliospheric latitude in the first part of 1976 rather than at 16°N it would have observed a well-defined two-sector structure. Second. Although Pioneer XI did observe an interplanetary field polarity that was predominantly away from the sun, we would predict that for intervals of a few days corresponding to Carrington solar longitudes near 35° and 160° Pioneer XI may have observed toward polarities. We note in Figure 2 of Smith et al. (8) that during the interval of interest Pioneer XI observed that the ratio of the number of away polarity observations to the total number of observations was about 0.8. The computed current sheet in Figure 2 would correspond to a ratio of about 0.7.

We suggest that the observations of the interplanetary magnetic field polarity by Pioneer XI and by Helios I and II support the viewpoint that the large-scale structure of the warped heliospheric current sheet can be computed from the observed photospheric magnetic field, with the ballerina effect perhaps adding small-scale ripples. Since coronal holes are effects of conditions pertaining to the large-scale photospheric magnetic configuration (6) the influence of coronal holes on the warped current sheet is to a considerable extent already included in the present calculations.

The observations by Pioneer XI at 16° North heliospheric latitude (8) have been widely misinterpreted to mean that the heliospheric current sheet is almost parallel to the solar equatorial plane (see for example 13). Figure 2 shows that even near the minimum of the eleven year sunspot cycle the current sheet probably

reached appreciable south heliospheric latitudes, and the considerations discussed by Svalgaard and Wilcox (2) indicate that near the maximum of the sunspot cycle the current sheet reaches heliographic latitudes of 50° or more (3).

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Figure Captions

Figure 1 An artist's impression of the warped heliospheric current sheet. Presently the region above the current sheet has interplanetary magnetic field (IMF) directed away from the sun and the region below has field directed toward the sun. (Artist: Werner Heil)

Figure 2 The curved line represents the calculated average heliospheric current sheet for the 5 rotations including January 20 through May 23, 1976. The dashed line at 16° N latitude represents the approximate heliographic latitude of the Pioneer XI spacecraft which was about 4 A.U. from the sun. The plus (away from the sun) and minus (toward) signs indicate the IMF polarity measured at Helios I and II projected back onto the solar corona. The observed IMF polarities agree well with the computed current sheet.

Figure 3 The same as Figure 2, except that the pluses and minuses represent the inferred IMF polarity at Earth mapped back to the solar corona. The observed polarity changes occur near crossings of the computed current sheet

100-101-102-103-104-105-106-107-108-109-110-111-112-113-114-115-116-117-118-119-120-121-122-123-124-125-126-127-128-129-130-131-132-133-134-135-136-137-138-139-140-141-142-143-144-145-146-147-148-149-150-151-152-153-154-155-156-157-158-159-160-161-162-163-164-165-166-167-168-169-170-171-172-173-174-175-176-177-178-179-180-181-182-183-184-185-186-187-188-189-190-191-192-193-194-195-196-197-198-199-200-201-202-203-204-205-206-207-208-209-210-211-212-213-214-215-216-217-218-219-220-221-222-223-224-225-226-227-228-229-230-231-232-233-234-235-236-237-238-239-240-241-242-243-244-245-246-247-248-249-250-251-252-253-254-255-256-257-258-259-260-261-262-263-264-265-266-267-268-269-270-271-272-273-274-275-276-277-278-279-280-281-282-283-284-285-286-287-288-289-290-291-292-293-294-295-296-297-298-299-300-301-302-303-304-305-306-307-308-309-310-311-312-313-314-315-316-317-318-319-320-321-322-323-324-325-326-327-328-329-330-331-332-333-334-335-336-337-338-339-340-341-342-343-344-345-346-347-348-349-350-351-352-353-354-355-356-357-358-359-360-361-362-363-364-365-366-367-368-369-370-371-372-373-374-375-376-377-378-379-380-381-382-383-384-385-386-387-388-389-390-391-392-393-394-395-396-397-398-399-400-401-402-403-404-405-406-407-408-409-410-411-412-413-414-415-416-417-418-419-420-421-422-423-424-425-426-427-428-429-430-431-432-433-434-435-436-437-438-439-440-441-442-443-444-445-446-447-448-449-450-451-452-453-454-455-456-457-458-459-460-461-462-463-464-465-466-467-468-469-470-471-472-473-474-475-476-477-478-479-480-481-482-483-484-485-486-487-488-489-490-491-492-493-494-495-496-497-498-499-500-501-502-503-504-505-506-507-508-509-510-511-512-513-514-515-516-517-518-519-520-521-522-523-524-525-526-527-528-529-530-531-532-533-534-535-536-537-538-539-540-541-542-543-544-545-546-547-548-549-550-551-552-553-554-555-556-557-558-559-560-561-562-563-564-565-566-567-568-569-570-571-572-573-574-575-576-577-578-579-580-581-582-583-584-585-586-587-588-589-590-591-592-593-594-595-596-597-598-599-600-601-602-603-604-605-606-607-608-609-610-611-612-613-614-615-616-617-618-619-620-621-622-623-624-625-626-627-628-629-630-631-632-633-634-635-636-637-638-639-640-641-642-643-644-645-646-647-648-649-650-651-652-653-654-655-656-657-658-659-660-661-662-663-664-665-666-667-668-669-670-671-672-673-674-675-676-677-678-679-680-681-682-683-684-685-686-687-688-689-690-691-692-693-694-695-696-697-698-699-700-701-702-703-704-705-706-707-708-709-710-711-712-713-714-715-716-717-718-719-720-721-722-723-724-725-726-727-728-729-730-731-732-733-734-735-736-737-738-739-740-741-742-743-744-745-746-747-748-749-750-751-752-753-754-755-756-757-758-759-760-761-762-763-764-765-766-767-768-769-770-771-772-773-774-775-776-777-778-779-780-781-782-783-784-785-786-787-788-789-790-791-792-793-794-795-796-797-798-799-800-801-802-803-804-805-806-807-808-809-810-811-812-813-814-815-816-817-818-819-820-821-822-823-824-825-826-827-828-829-830-831-832-833-834-835-836-837-838-839-840-841-842-843-844-845-846-847-848-849-850-851-852-853-854-855-856-857-858-859-860-861-862-863-864-865-866-867-868-869-870-871-872-873-874-875-876-877-878-879-880-881-882-883-884-885-886-887-888-889-890-891-892-893-894-895-896-897-898-899-900-901-902-903-904-905-906-907-908-909-910-911-912-913-914-915-916-917-918-919-920-921-922-923-924-925-926-927-928-929-930-931-932-933-934-935-936-937-938-939-940-941-942-943-944-945-946-947-948-949-950-951-952-953-954-955-956-957-958-959-960-961-962-963-964-965-966-967-968-969-970-971-972-973-974-975-976-977-978-979-980-981-982-983-984-985-986-987-988-989-990-991-992-993-994-995-996-997-998-999-1000

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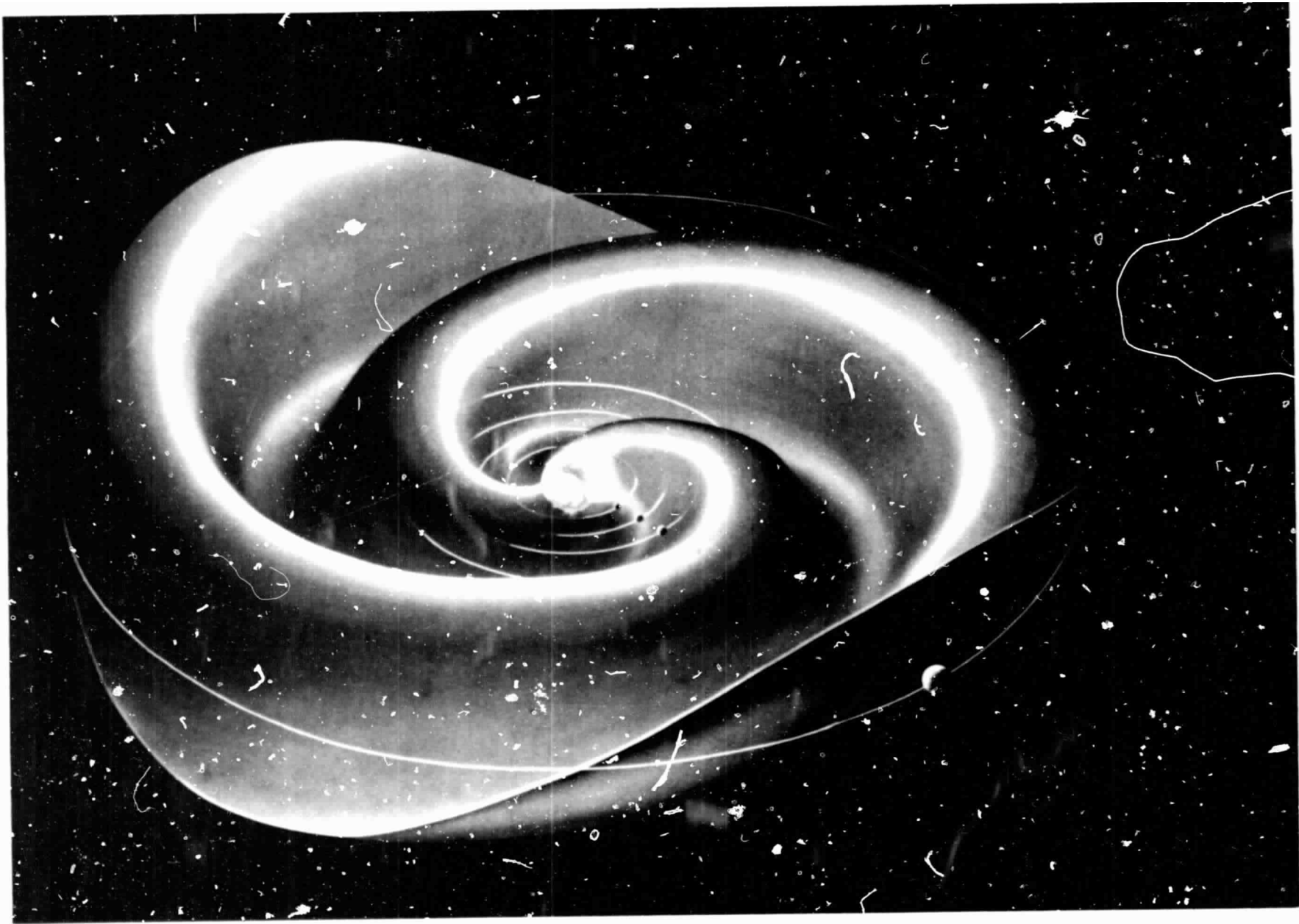


Figure 1

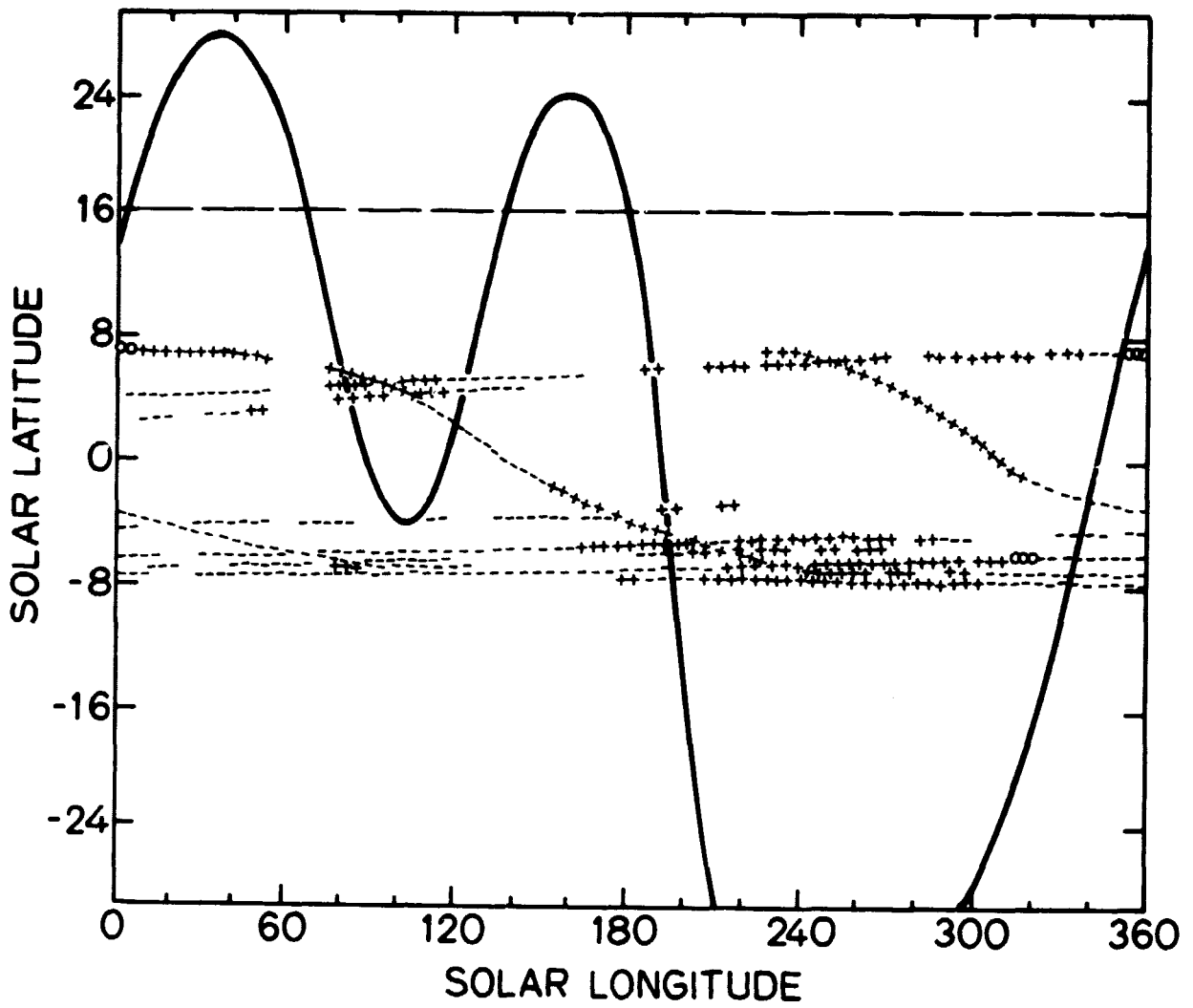


Figure 2

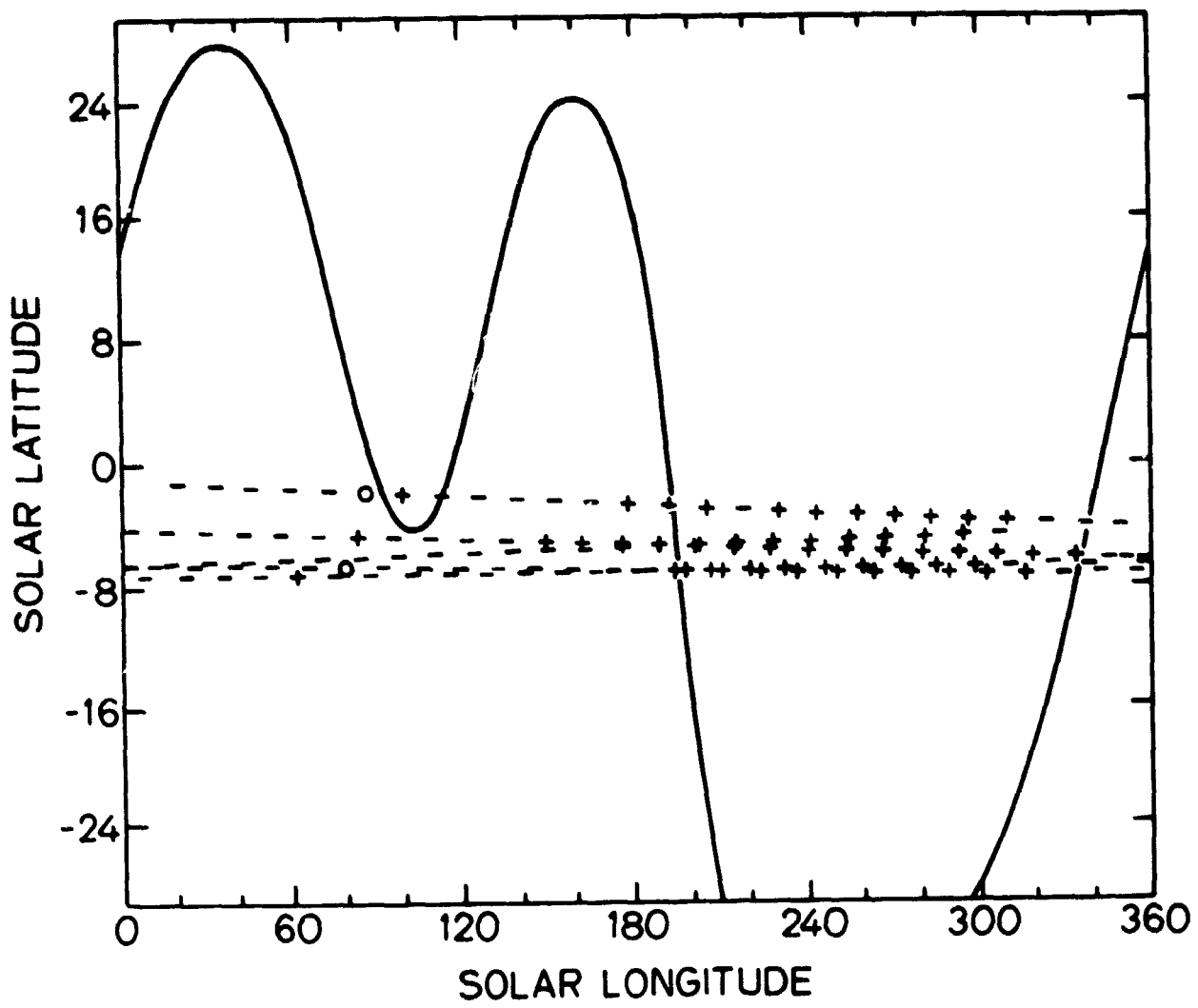


Figure 3