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The Space Infrared Telescope Facility (SIRTF) had – since June 1995 – planned to launch on December 1, 2001 aboard a Delta 7920H launch vehicle. In the baseline, the Delta placed SIRTF into an Earth-trailing solar orbit after flying a launch trajectory known as "direct ascent". Due to recent events the project has been forced to delay launch by 7.5 months until July 15, 2002. Despite the date change, the project is still baselining the 7920H and the solar orbit, but "direct ascent" can no longer be used because it does not lead to viable solar orbits for SIRTF. This paper examines why direct ascent is not an option for the summer launch, presents the new launch/injection strategy, and discusses the solar orbit optimization criteria used to define viable solar orbits.

INTRODUCTION

The Space Infrared Telescope Facility (SIRTF) is a cryogenically-cooled observatory for infrared astronomy. It is both a companion of NASA's other Great Observatories and a cornerstone of NASA's Origins program. SIRTF will be launched from Space Launch Complex 17 at Cape Canaveral Air Force Station (CCAFS) aboard a Delta 7920H on July 15, 2002 into an Earth-trailing solar orbit. During its 2.5 to 5-year lifetime SIRTF will take maximum advantage of the solar orbit as it dramatically advances our understanding of the Universe.

WHY THE SOLAR ORBIT

SIRTF will be the first mission to fly the "solar orbit" even though the characteristics of this orbit are so compelling that many missions – STEREO, Starlight, and SIM to name a few – are adopting it as their baseline trajectory. This is despite the fact that the mission trajectories can vary wildly from one mission to the other. For SIRTF, the solar orbit is compelling for a number of reasons. Because the solar orbit causes recession from the Earth/Moon system, the Observatory is outside the Earth's trapped radiation environment, its thermal environment is greatly improved, Earth/Moon avoidance constraints are minimized, and the full sky is available for viewing every 6 months. Equally forceful arguments can be made for the solar orbit because it: limits the reliance on batteries since the Observatory is always (after the launch phase) in full sunlight, requires no onboard propellant for stationkeeping or trajectory correction, and promotes simplified deep space tracking, fault protection, and observation planning designs. And finally, the launch energies (C_3) required to achieve most solar orbits are so low (typically between

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$0.3\ km^2/s^2$ and $1.0\ km^2/s^2$) that the mass performance is much greater than that associated with the overwhelming majority of interplanetary trajectories.

The one major drawback inherent to the solar orbit is that it requires a very capable telecom system for communications with Earth. SIRTF relies on a 1.35-meter diameter, bodyfixed High Gain Antenna (HGA) for its high rate communications. These data rates, the highest of which is 2.2 Mbps, allow SIRTF to download roughly 8 Gbits of data during two, 1-hour communication sessions every day during its main mission. Emergency (safemode) and early mission communications are carried out via the Observatory's system of Low Gain Antennas (LGAs).

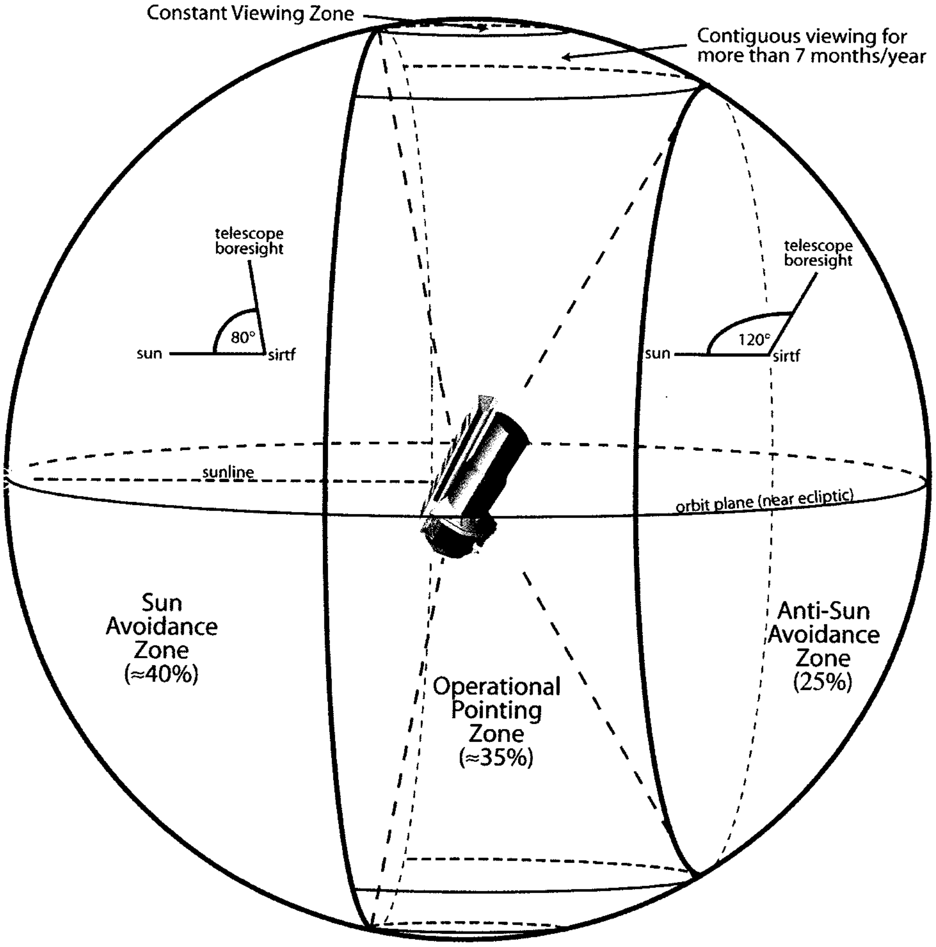


Figure 1 Instantaneous Pointing Zones and Sky Coverage Percentages

SOLAR ORBIT OPTIMIZATION CRITERIA

Many of the desirable characteristics of the solar orbit have been listed above but the story is not complete without determining how much the orbit can be tailored to conform to the constraints of a given mission design. In SIRTF's case, the biggest factor in insuring the safety of the Observatory and in maximizing observing efficiency comes from making sure that pointing constraints are adhered to at all times. Solar exposure to the Observatory's sensitive instruments and optics or to its low emissivity surfaces is **not** allowed. Furthermore, after the initial hour following separation from the launch vehicle, the trajectory geometry coupled with the pointing constraints shall not preclude the use of the LGAs for safemode communications. The solar orbit chosen for SIRTF is the one that best accommodates these pointing and telecommunications constraints.

OPZ Definition

The pointing constraints most important to SIRTF are explained graphically in Figure 1 which depicts how the entire sky can be divided into 3 zones at any instant in time during the mission. SIRTF's instruments are so sensitive that the Observatory boresight (Observatory +X axis) can not be pointed any closer than 80° toward the Sun. This exclusion region is known as the Sun Avoidance Zone. Furthermore, +X can not be pointed more than 120° from the sunline. This constraint serves both to keep sunlight off the radome covering the HGA and to insure that the flux incident on the solar arrays is maintained within levels needed for powering the Observatory. This pointing exclusion region is known as the Anti-Sun Avoidance Zone. The region of sky between these two zones is the Operational Pointing Zone or OPZ. The edges of the OPZ move roughly 1°/day as SIRTF orbits the Sun. This means that targets in the plane of SIRTF's orbit (which is nearly coplanar with the ecliptic) are within the OPZ for 40 days at a time. As can be seen in Figure 1, targets stay within the OPZ longer and longer the further they are from the orbit plane. Targets that are more than 80° from the ecliptic can always be seen by SIRTF. These targets lie within the Constant Viewing Zone or CVZ.

Not shown in Figure 1 is the fact that the XZ-plane (+Z points through the apex of the solar panels) must remain within two degrees of the sunline at all times, even when pointing at targets within the OPZ. This roll constraint is extremely important to maintain but it does not play a roll in trajectory selection. Also not visible are the boresights of the transmit and receive LGAs which are parallel to the +Y axis, with a second pair of transmit and receive LGAs along the –Y axis. The HGA is mounted below the spacecraft bus.

Telecom Constraints

In the SIRTF mission design the intense instrument-commissioning activities beginning on Day 30 of the In Orbit Checkout (IOC) period require the highest (HGA) downlink rates available. In early 1997 the HGA boresight, which had previously been aligned with the –X axis, was canted by 8° (from -X toward +Z). Canting the boresight in this manner allows the HGA to be used earlier in IOC, but unfortunately decreases the maximum allowable Sun-Probe-Earth (SPE) angle by an equal amount. During HGA communication sessions +X must point within the OPZ ($80° \leq \alpha \leq 120°$), which means that the Sun-Probe-Earth (SPE) angle is constrained. Namely,

$$80° \leq \alpha \leq 120°$$

$$80° \leq [(180°\text{-SPE}) - 8°] \leq 120°$$

$$52° \leq \text{SPE} \leq 92° \qquad (1)$$

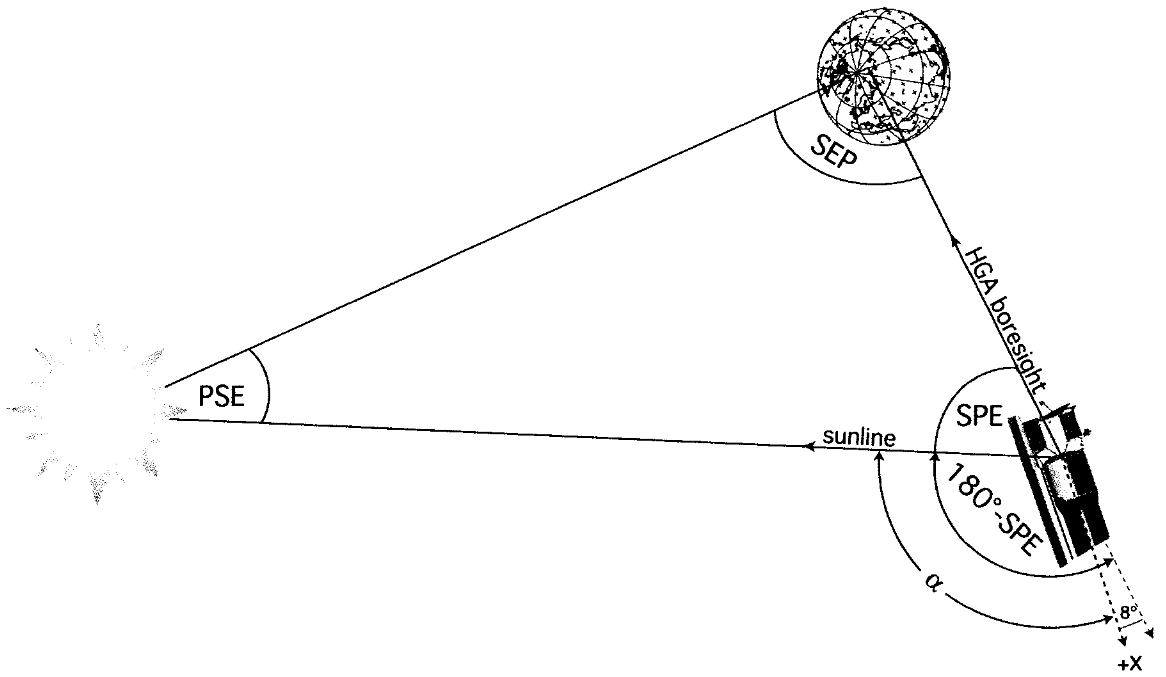


Figure 2 HGA Communications Attitude and Sun-Earth-SIRTF Plane Description

The SIRTF telecom system is sized to provide +2 dB of link margin for safemode (emergency) communications out to a maximum range of 0.64 AU. Safemode communications are through the LGAs, they occur while the Observatory spins at 1/2 revolution/hour about the sun-pointed +Z axis, and they require at least 5 downlink frames per hour to aid in diagnosing the emergency. Furthermore, all LGA communications are constrained by the field pattern of the antennas which limit the LGA Fields-of-View (FOV) to within 60° of each boresight. All of these telecom constraints translate into design requirements on the characteristics of the solar orbit that SIRTF will fly during the 5 year and 2 month nominal mission. These requirements are summarized in Table 1.

Table 1

TELECOM AND POINTING RESTRICTIONS MAPPED TO ORBIT REQUIREMENTS

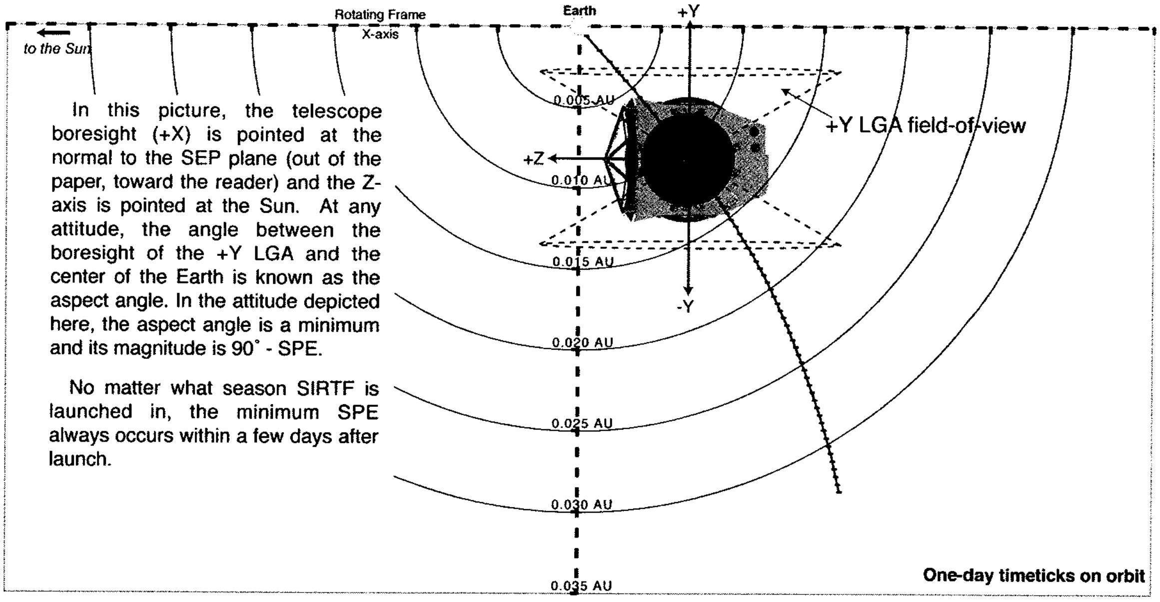
1. The maximum drift distance is 0.64 AU,
2. The SPE must be at least 52° by Day 30 and may never dip below 52° for the rest of the nominal mission,
3. The maximum allowable SPE angle is 90° (the maximum value in Eq. (1) plus some margin to account for injection error[1]),
4. The minimum allowable SPE angle is 36°.

The constraint on the minimum SPE is derived from the desire to have at least 5 downlink frames per hour in safemode. If the Observatory enters safemode while in the attitude depicted in Figure 3, then the "yaw" angle (2θ) about the sunline which keeps the Earth within an LGA FOV helps to determine the minimum SPE through the relationship given by:

$$\theta = \cos^{-1}(\cos(\phi)/\sin(\mathrm{SPE})) \qquad (2)$$

where $\phi = 60°$ is the angle between an LGA boresight and the edge of its FOV

Using Eq. (2) and the safemode downlink rate of 40 bps, frame size of 10,112 bits, and rotation rate of 0.05 deg/sec, it is easy to find the minimum allowable SPE.



In this picture, the telescope boresight (+X) is pointed at the normal to the SEP plane (out of the paper, toward the reader) and the Z-axis is pointed at the Sun. At any attitude, the angle between the boresight of the +Y LGA and the center of the Earth is known as the aspect angle. In the attitude depicted here, the aspect angle is a minimum and its magnitude is 90° - SPE.

No matter what season SIRTF is launched in, the minimum SPE always occurs within a few days after launch.

Figure 3 **LGA Communication Geometry With Respect to the Sun-Earth-SIRTF Plane**

DIRECT ASCENT

In June 1995 the SIRTF project officially adopted "direct ascent" as its baseline launch vehicle trajectory. Direct ascent was chosen because it delivered the maximum payload mass to a given C_3 (minimized gravity loss). In direct ascent, the event timeline up to the "SECO–1" event, i.e., from liftoff to the first cutoff of the Second Engine, is the same as it is for any other interplanetary mission using the 7920H. The same, that is, except that there is no SECO-1 event for direct ascent. Once the second engine ignites it burns all the way to completion. The whole sequence between launch and final cutoff of the second engine takes 709 seconds for SIRTF.

Since there is no coast phase, the Declination of the Launch (Outgoing) Asymptote (DLA) can not be changed. The DLA for SIRTF is -24.74° with respect to the Earth's true equator at injection, no matter what time of day or on what day the launch occurs.

In November 1996, Boeing (formerly McDonnell Douglas) performed a run of their GVPAT trajectory software to generate a baseline direct ascent flight path for the SIRTF project.[2] The injection targets included a C_3 of 0.4 $\mathrm{km}^2/\mathrm{s}^2$ and the DLA given in the previous paragraph. The Right Ascension of the Launch (Outgoing) Asymptote (RLA) was not specified but was to be calculated based on a launch epoch of 14:38:06 (UTC) on March 1, 2002.

The important data from the Boeing run was not that the supplied injection targets led to a viable solar orbit (which they didn't), but that the injection state could be used to find viable solar orbits. This was accomplished by writing software using JPL's astrodynamic calculator (Quick) that rotated the Boeing-supplied injection state vector to any time before or after the epoch of the original injection. This process was used to simulate a direct ascent launch on any given launch day without having to run GVPAT over and over. Hundreds of thousands of new injection states and injection epochs have since been fed into FAST (JPL's medium precision trajectory integrator) and propagated for 5 years and 2 months. Forces modeled in the propagation include the gravitational influence of the Earth, Sun, Moon and all the planets, J_2 and J_3 when in the vicinity of the Earth, and a flat plate solar pressure model. Each propagated trajectory was saved and searched (using more Quick routines) for the characteristics of interest to SIRTF. A one-line summary was then saved for each trajectory, and those trajectories that best satisfied the optimization criteria (Table 1) were used to establish a baseline launch period (75 days beginning on 12/1/2001). Table 2 lists the best direct ascent solutions on a weekly basis for launches between December 1, 2001 and March 1, 2002, even though some of these solutions violate one or more of the optimization criteria (shaded cells).

Table 2

BEST DAILY SOLAR ORBIT SOLUTIONS FOR DIRECT ASCENT LAUNCHES FROM 12/01/2001 TO 03/01/2002

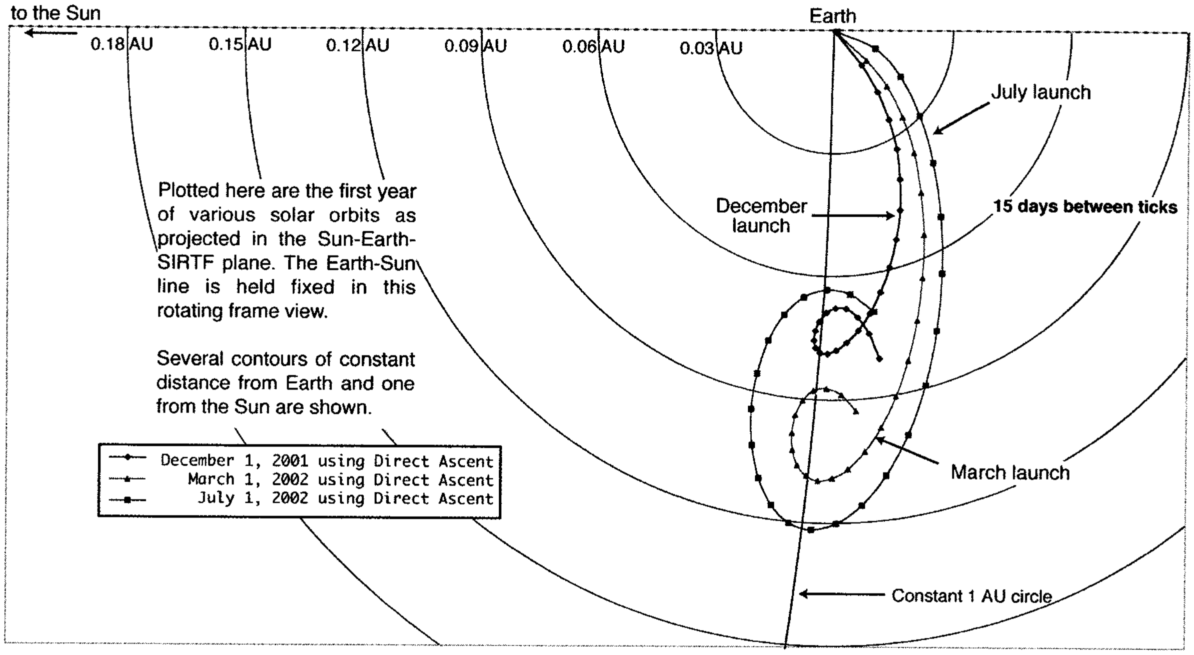
C_3 (km^2/s^2)	J2000 DLA (deg)	J2000 RLA (deg)	Ecliptic Clock Angle (deg)	Ecliptic Cone Angle (deg)	Min SPE (deg)	Days Until Min. SPE	HGA Start Day	Max SPE (deg)	Max. Range of Probe to Earth (AU)	Launch Date	Predicted Launch Time (UTC)
0.40	-24.80	69.78	173.45	-46.36	49.32	5	26	89.36	0.6215	12/01/01	15:48:00
0.40	-24.80	74.68	172.74	-47.15	50.37	7	23	89.22	0.6196	12/08/01	15:40:00
0.40	-24.80	79.57	172.14	-47.73	51.21	7	17	88.04	0.6342	12/15/01	15:32:00
0.40	-24.80	85.97	173.66	-48.16	51.61	7	12	87.31	0.6422	12/22/01	15:30:00
0.40	-24.80	91.36	173.89	-48.23	51.83	7	11	88.07	0.6288	12/29/01	15:24:00
0.40	-24.80	96.01	173.07	-48.06	51.91	10	14	88.61	0.6201	01/05/02	15:15:00
0.40	-24.79	100.65	172.21	-47.70	51.80	10	15	88.07	0.6266	01/12/02	15:06:00
0.40	-24.79	106.80	173.23	-46.92	51.24	9	17	87.63	0.6317	01/19/02	15:03:00
0.40	-24.79	112.69	173.74	-45.88	50.32	9	26	88.75	0.6171	01/26/02	14:59:00
0.40	-24.79	117.84	173.08	-44.75	49.51	10	31	89.89	0.6029	02/02/02	14:52:00
0.40	-24.79	122.73	171.93	-43.51	48.58	10	32	90.04	0.6018	02/09/02	14:44:00
0.40	-24.79	129.13	172.34	-41.67	47.09	9	36	89.88	0.6044	02/16/02	14:42:00
0.40	-24.79	137.53	174.63	-38.94	44.03	8	45	90.21	0.5969	02/23/02	14:48:00
0.40	-24.79	144.95	176.42	-36.30	41.14	9	54	90.14	0.6047	03/01/02	14:54:00

The first five columns in Table 2 summarize the injection targets. The direction of the outgoing $\mathbf{V}_\infty$ vector is expressed in both J2000 coordinates and Ecliptic Clock/Cone coordinates. Ecliptic Clock is defined as the angle in the ecliptic plane between the Earth-Sun line and the projection of $\mathbf{V}_\infty$. Ecliptic Cone is the angle between $\mathbf{V}_\infty$ and the ecliptic plane, positive values indicating that the outgoing asymptote is above the ecliptic. At such low values of C_3 (V_∞^2), empirical evidence shows that all viable solar orbits during the launch dates that were studied have Ecliptic Clock values between 172° and 177° and magnitudes of Ecliptic Cone between 45° and 54°.

Sharer uses a similar parameterization for the components of $\mathbf{V}_\infty$, except that his reference direction is the Earth's heliocentric velocity vector.[3] I find it easier to describe the injection situation if it can be referred back to the sunline. For example, the injection point for the Earth-lagging solar orbit occurs near local noon and the injection point for the Earth-leading solar orbit occurs near local midnight. Hence Ecliptic Clock and Cone.

The next five columns in Table 2 summarize the solar orbit for a given set of injection targets. "HGA Start Day" is the day after launch when SPE = 52°. The remaining column headings in Table 2 should be self-explanatory.

SIRTF can not launch on a given day if more than one of the optimization criteria go unsatisfied, although some of the criteria carry more weight than others. In particular, there is no daily launch solution if the minimum SPE constraint is violated. Interestingly enough, the launch dates having the lowest drift rates have the worst performance in all other areas. This is illustrated in Figure 4 which compares the first year of solar orbits resulting from the "best" direct ascent launches in three different seasons. The December 1st and March 1st orbits are summarized in Table 2. The July 1st orbit has major violations of every one of the optimization criteria except drift rate (the maximum range is 0.564 AU). Only the first year of each orbit is shown.



Plotted here are the first year of various solar orbits as projected in the Sun-Earth-SIRTF plane. The Earth-Sun line is held fixed in this rotating frame view.

Several contours of constant distance from Earth and one from the Sun are shown.

Figure 4 **Solar Orbit Comparison for Direct Ascent Launches in Different Seasons**

The Importance of DLA

The early trajectory work that Ocampo did in 1991 to prove the solar orbit concept for SIRTF relied on the Circular Restricted Three-Body Problem (CRTBP) to model the solar orbit dynamics.[4] At the time the formulation limited motion to the ecliptic plane so little was discovered about the characteristics of orbits which had injection targets with an appreciable out-of-plane component. It turns out that it is this out-of-plane component that SIRTF relies upon. The Observatory's orbit becomes slightly inclined (approximately 1°) with respect to the ecliptic when the magnitude of Ecliptic Cone is more than 45° and $C_3 = 0.4\ \mathrm{km}^2/\mathrm{s}^2$. Motion in an inclined orbit serves to reduce the maximum value of SPE[3], as well as to keep the minimum value of SPE from getting too low. As an example, in Figure 4 the Ecliptic Cone for the December 1, 2001 launch is -46.36°, the minimum SPE is 49.32° and the maximum SPE is 89.36°. In stark contrast, the Ecliptic Cone for the July 1, 2002 direct ascent launch is -1.41°, the minimum SPE is 16.57° and the maximum SPE is 98.14°. SIRTF can not use the July 1st direct ascent solution, but it is interesting to note that the HGA start date for this launch is Day 64 and the SPE is greater than 92° for 100 days starting on Day 232.

In addition to the inability to change DLA when using direct ascent, the flight path of the Observatory immediately following separation is very bad from a communications standpoint. SIRTF's near-earth trajectory for each of the launches shown in Table 2 does not place the Observatory above the transmit mask of any DSN station until more than 4 hours after launch (see Figure 5). SIRTF's review boards were never comfortable with this long communication blackout period during such a critical phase, and after the Mars Polar Lander failure they became even more sensitized to it. As a consequence, SIRTF made plans to have supplemental ground station coverage provided by an antenna in Hartebeesthoek, South Africa.

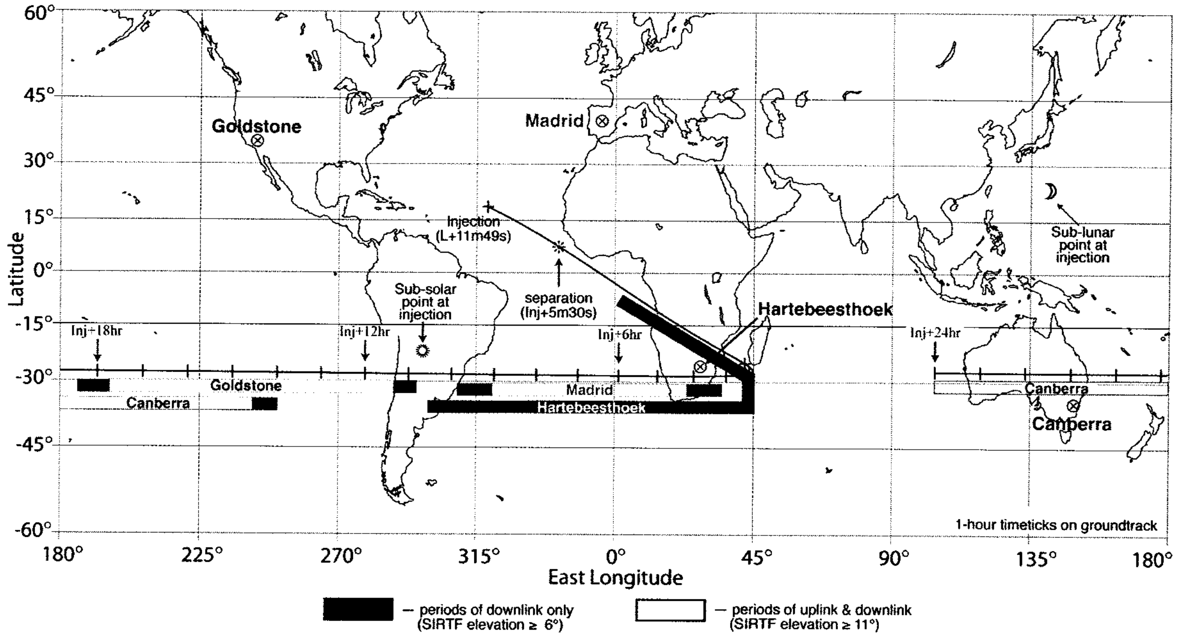


Figure 5 Direct Ascent Groundtrack and Viewperiods from Injection to Inj. + 1 Day on 12/1/2001

THE NEW BASELINE

It may have been careful planning or extreme luck that SIRTF was baselining both direct ascent and a December launch, but whatever it was it did not hold when the launch date slipped to July 15, 2002. The effort spent trying to make direct ascent work throughout the entire year was not in vain, however, because it clearly showed the need to increase the angle between $\mathbf{V}_\infty$ and the ecliptic plane for the solar orbit to be viable for SIRTF. For a summer launch on the 7920H the only way to significantly increase this angle is to target a DLA that is well above the Earth's equator (vs. one that is well below the equator).

A fortuitous decision was made in late 1999 to have Boeing perform another GVPAT run, but this time for a July 1, 2002 launch. The analysis was requested because the project wanted to learn how it could keep its promise of being able to launch on any day of the year. This analysis would calculate the maximum mass that could be delivered to the original C_3 after a coast period of 45 minutes between Second Engine firings. Forty-five minutes was chosen simply because it was felt that SIRTF would never need to coast for longer than this, i.e., half an orbit. Again, it was not important to specify either DLA or RLA at this time because it was known that they could be easily specified later should the parking orbit launch/ascent scenario prove necessary.

The Boeing analysis and related report were ready in January 2000 and showed that the 7920H could easily deliver SIRTF to a $C_3 = 0.4$ km^2/s^2 after spending 45 minutes in a parking orbit. The mass margin **after** reserving the over 400 fps (feet per second) required for a 99.7% Probability of Command Shutdown (PCS) was roughly 100 kg.[5] Although the DLA attainable for this scenario (23.32°, J2000) was not optimal for a July 1st launch, the trajectory data included in the report could be used to help find the optimum.

Software that had been written in Quick for the Cassini mission was obtained and modified to simulate going from a parking orbit to a solar orbit via an instantaneous injection burn. This software helps determine the planar launch time necessary to achieve user-supplied injection targets. It also provides an injection state and epoch that can be propagated in FAST and run through the existing search tools – exactly as was done for the direct ascent scenario. The new front end software solves the launch time and injection state problems through its knowledge of the launch site location, launch azimuth, time between launch and SECO-1, central angle swept out between launch and SECO-1, the orbital elements of the parking orbit and of course the injection targets. Everything but the injection targets, which are input by the user, is obtained from data given in the GVPAT output. When tested against the injection targets obtained in Reference 5, the new software predicted the launch time to within 4 minutes of the actual launch time and the injection time to within two minutes. Table 3 shows sample output for the new solar orbit search software.

As was mentioned previously, the new software allows the user to vary C_3, DLA, and RLA until the optimum solar orbit is found, whereas the direct ascent search routines allowed only RLA (launch time) to change. As can be seen in Table 3, viable solar orbits can result from a fairly wide range of injection targets. Nominal injection targets can be chosen so that even 3σ injections lead to viable solar orbits for SIRTF.[1]

Since DLA doesn't change for direct ascent, the relative timing and body-fixed location of every launch vehicle event is the exact same on every day during the original 75-day launch period. This property is extremely desirable because it greatly simplifies the interface between the project and launch vehicle contractor and aids the process of validating and verifying the injection targets.

Table 3

SAMPLE SOLAR ORBIT SEARCH OUTPUT USING VARIOUS INJECTION TARGETS ON JULY 15, 2002

C_3 (km^2/s^2)	J2000 DLA (deg)	J2000 RLA (deg)	Ecliptic Clock Angle (deg)	Ecliptic Cone Angle (deg)	Min SPE (deg)	Days Until Min. SPE	HGA Start Day	Max SPE (deg)	Max. Range of Probe to Earth (AU)	Launch Date	Planar Launch Time (UTC)
0.3	26.5	280	171.2	49.5	52.15	4	0	87.01	0.6642	7/15/02	6:51:02
0.3	26.5	282	173.9	49.3	51.23	4	13	86.52	0.6579	7/15/02	6:59:00
0.3	26.5	284	176.6	49.0	50.37	4	21	86.13	0.6667	7/15/02	7:06:58
0.3	28.5	280	171.6	51.4	54.70	6	0	86.28	0.6736	7/15/02	5:42:20
0.3	28.5	282	174.4	51.2	53.80	6	0	85.89	0.6661	7/15/02	5:50:17
0.3	28.5	284	177.1	51.0	52.95	7	0	85.61	0.6735	7/15/02	5:58:13
0.4	26.5	280	171.2	49.5	52.00	4	6	90.23	0.6341	7/15/02	6:51:02
0.4	26.5	282	173.9	49.3	51.09	4	14	89.11	0.6229	7/15/02	6:59:00
0.4	26.5	284	176.6	49.0	50.25	4	23	88.24	0.6315	7/15/02	7:06:58
0.4	28.5	280	171.6	51.4	54.49	6	0	89.37	0.6412	7/15/02	5:42:20
0.4	28.5	282	174.4	51.2	53.61	6	0	88.42	0.6302	7/15/02	5:50:17
0.4	28.5	284	177.1	51.0	52.77	7	0	87.68	0.6382	7/15/02	5:58:13
0.5	26.5	280	171.2	49.5	51.87	4	7	93.27	0.6193	7/15/02	6:51:02
0.5	26.5	282	173.9	49.3	50.98	4	15	91.48	0.5982	7/15/02	6:59:00
0.5	26.5	284	176.6	49.0	50.16	4	24	90.15	0.6042	7/15/02	7:06:58
0.5	28.5	280	171.6	51.4	54.32	6	0	92.28	0.6230	7/15/02	5:42:20
0.5	28.5	282	174.4	51.2	53.45	6	0	90.7	0.6045	7/15/02	5:50:17
0.5	28.5	284	177.1	51.0	52.63	7	0	89.53	0.6109	7/15/02	5:58:13

Keeping the same body-fixed trajectory was desired for the new launch period but could not be realized because a single DLA could not be found that gave viable solar orbits throughout the entire launch period (60 days). It also turns out that the 7920H trajectory achieving the maximum Parking Orbit Inclination (POI) could not be used throughout because requirements on the length of time spent in shadow and the amount of solar illumination input to the Observatory's cold surfaces could not be satisfied. The best compromise solution was to span the launch period using three separate ascent trajectories, each targeting a single DLA. Boeing is currently performing the mission analysis necessary to calculate how well the 7920H meets SIRTF's injection requirements.

Several sets of injection targets and solar orbit results during the new 60-day launch period are shown in Table 4. This new launch period is limited because the maximum DLA that the 7920H can deliver the Observatory to is 36.3°. As the date gets closer to

Autumnal Equinox and the Sun gets closer to the equatorial plane, the minimum necessary DLA with respect to the equator grows to 45°. For this reason the current SIRTF launch period runs from July 15, 2002 to September 11, 2002. Launches can pick up again after the equinox by targeting negative DLAs, but there is currently no requirement to extend the launch period beyond 60 days.

Table 4

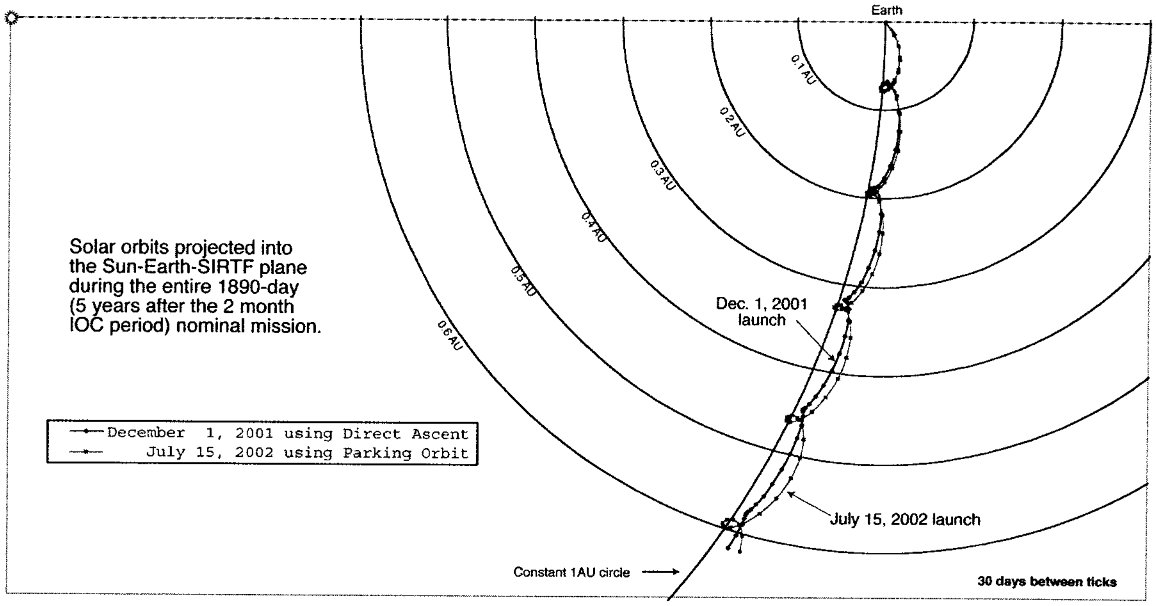
SOLAR ORBIT SEARCH OUTPUT FOR THE NEW LAUNCH PERIOD, 7/15/2002 TO 9/11/2002

C_3 (km^2/s^2)	J2000 DLA (deg)	J2000 RLA (deg)	Ecliptic Clock Angle (deg)	Ecliptic Cone Angle (deg)	Min SPE (deg)	Days Until Min. SPE	HGA Start Day	Max SPE (deg)	Max. Range of Probe to Earth (AU)	Launch Date	Planar Launch Time (UTC)
0.4	27.0	282	174.0	49.7	51.68	4	10	88.94	0.6246	7/15/02	6:47:15
0.4	27.0	287	175.1	49.1	50.96	5	17	89.82	0.6136	7/21/02	6:43:35
0.4	27.0	293	176.3	48.0	50.01	6	31	90.00	0.6089	7/28/02	6:39:57
0.4	31.5	292	175.7	52.5	54.92	13	0	89.13	0.6187	7/29/02	6:52:33
0.4	31.5	295	174.0	51.9	54.50	12	0	89.50	0.6179	8/04/02	6:40:53
0.4	31.5	302	175.4	50.1	52.99	9	0	88.75	0.6269	8/12/02	6:37:15
0.4	31.5	309.25	176.5	47.9	50.90	9	27	89.95	0.6126	8/20/02	6:34:36
0.4	36.3	308	177.0	52.7	55.56	11	0	88.73	0.6265	8/21/02	7:13:23
0.4	36.3	313	176.1	51.0	53.94	16	0	89.70	0.6147	8/28/02	7:05:43
0.4	36.3	318.75	174.9	49.0	52.23	12	0	89.99	0.6132	9/05/02	6:57:06
0.4	36.3	325	175.7	46.6	50.32	10	28	89.96	0.6152	9/11/02	6:58:21

The trajectories in Table 4 targeting a DLA = 27° will all fly planar ascents from a launch azimuth of 95°. Those targeting DLA = 31.5° will fly planar ascents from a launch azimuth of 105°; and those targeting DLA = 36.3° will fly dogleg ascents from a launch azimuth of 105° (although the launch times in Table 4 are for planar launches). All of these launch/ascent scenarios place the Observatory within view of the DSN's Canberra station within one hour of launch. It should be noted that the above injection targets do not lead to the **best** solutions of the solar orbit criteria on each day of the launch period, but they do **satisfy** each of the criteria (except where noted). Additionally, all launches meet SIRTF's time in shadow and solar illumination requirements, and the fact that there are only three launch vehicle trajectories to model means that the target validation process is vastly simplified. All of these factors taken together (along with the early DSN pass) comprise the **trajectory optimization process** for SIRTF.

The New Mission Orbit

The solar orbit that results from a planar launch into a parking orbit on July 15, 2002 is very similar to that which resulted from a direct ascent launch on December 1, 2001. These two orbits are plotted in the rotating frame and shown in Figure 6.



Solar orbits projected into the Sun-Earth-SIRTF plane during the entire 1890-day (5 years after the 2 month IOC period) nominal mission.

Figure 6 Baseline Trajectory Comparison for 12/1/2001 and 7/15/2002 Launch Dates

SUMMARY AND CONCLUSION

When the SIRTF project was forced to slip its launch date it was known that the direct ascent launch vehicle trajectory could no longer be flown because it lead to unusable solar orbits for launches between mid-February 2002 and mid-November 2002. A preemptive mission analysis performed by Boeing (before the launch slip was announced) showed that the project did not have to rely on direct ascent to meet its injection target requirements. This mission analysis provided valuable performance data for the new solar orbit search software that was rapidly developed to help the project decide when the new launch could occur. Also contributing to the project's decision to choose a new launch date was the desire to keep its healthy risk reduction posture by maintaining a long launch period. This new software has been used to determine launch vehicle requirements that will be used to launch SIRTF over a period of 60 days beginning on July 15, 2002.

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