# STARSHINE MISSIONS IN 2001

Gil Moore
Starshine Headquarters, Monument, CO, 719-488-0721, gilmoore12@aol.com

William Braun
Naval Research Laboratory, Washington, DC, 202-767-0695, braun@space.nrl.navy.mil

Phillip Jenkins
NASA Glenn Research Center, Cleveland, OH, 216-433-2233, phil.jenkins@grc.nasa.gov

Walter Holemans
Planetary Systems Corporation, Silver Springs, MD, 301-495-0737

Donald Lefevre
Cynetics Corporation, Rapid City, SD, 605-394-6430, cynetics@rapidcom.com

Michael Batchelder
South Dakota School of Mines and Technology, Rapid City, SD, 605-394-2454
michael.batchelder@sdsmt.edu

**Abstract.** Two upgraded Starshine satellites will fly in the fall of 2001. Starshine 2 will fly on NASA's Space Shuttle Endeavor on November 29 and will carry 846 student-polished mirrors, 31 laser retro-reflectors, and a cold-gas spin system.

Starshine 3 will fly as the primary payload on NASA's Kodiak Star mission on August 31 out of Kodiak, AK. It will carry 1500 student-polished mirrors, 31 laser retroreflectors, an array of state-of-the-art solar cells and experimental integrated power supplies, and a VHF communication system. It will be deployed from the Athena I launch vehicle by a Lightband separation system.

## Introduction

The Starshine project is a combined educational outreach and atmospheric research program that is designed to measure the density of the upper atmosphere throughout a complete solar cycle. It involves flying a series of small, optically reflective, spherical satellites in low earth orbit over an eleven-year period and measuring their rates of orbital decay. A volunteer consortium of universities, government agencies, corporations, private individuals and students in elementary and secondary schools, led by the U.S. Naval Research Laboratory and the Space Grant Program, is building the satellites and certifying them for flight by NASA. The first satellite in the series was launched from a Space Shuttle on June 5, 1999, and it de-orbited on February 18, 2000, over the central Atlantic Ocean.

Figure 1
Sunlight Reflecting From One Starshine Mirror

Flashes of sunlight reflecting from Starshine 1's mirrors (Figure 1) were visually tracked at twilight by school children, and the satellite's aluminum shell was radar tracked by the U.S. Space Command. Project personnel computed the satellite's orbit from the tracking data and displayed the results on the project web site. They also provided a link on the web site to measurements of solar extreme ultraviolet radiation made by the NASA/ESA Solar Heliospheric Observatory spacecraft (SOHO).

Students calculated atmospheric density from the rate of decay of the satellite's orbit and plotted the density against solar EUV flux. In this manner, they have gained a basic understanding of the way the earth's upper atmosphere responded to fluctuations in solar EUV output over an eight-month period during the increasing phase of solar cycle 23 (Figure 2).

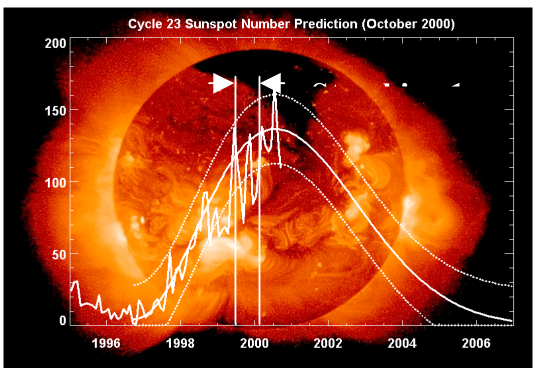


Figure 2
Sunspot Number Plot for 1st Half Solar Cycle 23

U.S. Government scientists are now starting to use the data from the Starshine 1 mission to refine orbit decay codes by factoring into them the effect of solar EUV flux. Beginning with the Starshine 2 and 3 missions in 2001, the International Satellite Laser Ranging Network will also track the satellites and provide significant improvements in satellite position measurement and orbit determination accuracy. In the following sections, the authors will describe the progression of design changes that are being made in the Starshine series to improve each satellite's usefulness as an atmospheric drag measuring device.

**Starshine 1**

The first Starshine satellite was completely passive. It was a hollow aluminum ball, 19 in (48 cm) in diameter and weighed 87 lb (38 kg). It was covered with 878 student-polished front-surface aluminum mirrors (Figure 3).

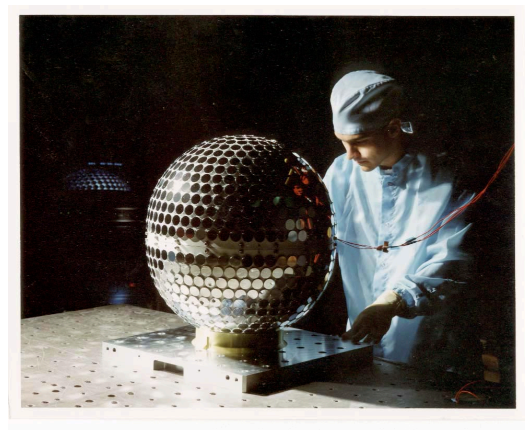

Figure 3
Starshine 1 Satellite on Vibration Table

**Starshine 2**

This satellite is the same size and mass as Starshine 1 (Figure 4). It carries 846 student-


Figure 4
Starshine 2 Satellite

polished mirrors on its external surface. It has been improved over the Starshine 1 design by the addition of a cold gas spin system consisting of a low-pressure Nitrogen gas container, stinger rod, microswitch, power box, latching valve, and two microthruster nozzles (Figure 5).

After the satellite is deployed from the orbiter, the stinger rod will extend and close the microswitch, which will open the latching valve and allow gas to flow through the nozzles to spin the satellite at a rate of 5 degrees per second.

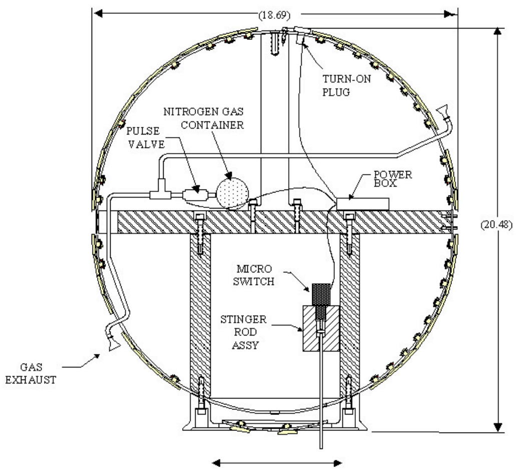


Figure 5
Starshine 2 Cutaway Drawing

The rotational motion will cause sunlight to reflect a brief flash every few seconds from the satellite's mirrors and provide an intermittent naked-eye point source for students to track through the star background at twilight. Some of the elements of the spin system are visible below (Figure 6).

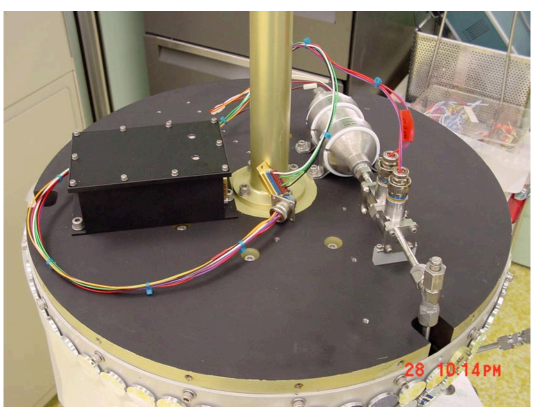


Figure 6
Cold Gas Spin System Elements

The second improvement built into Starshine 2 is the addition of 31 passive laser retroreflectors to its surface (Figure 7), so the satellite can be tracked to a high degree of precision by the International Satellite Laser Ranging Service.

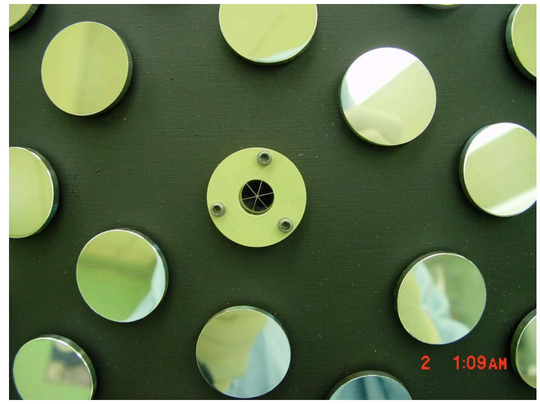


Figure 7
Laser Retroreflector and Student Mirrors

**Starshine 3**

A larger, much-improved Starshine 3 (Figure 8)


Figure 8
Starshine 3 Mirror Installation

will fly as the primary payload on NASA's Kodiak Star mission aboard a Lockheed Martin Athena 1 ELV out of Kodiak, Alaska, on August 31. It will be deployed into a 500 km circular orbit inclined 67 deg to the equator. Its orbital lifetime is expected to be four years. The satellite is 36 in (91 cm) in diameter and weighs 197 lb (89 kg). The structure consists of two spun aluminum shells and an aluminum sheet metal thrust cone supporting an aluminum honeycomb payload deck (Figure 9). This satellite will serve as a test bed for demonstrating several innovations of interest to the small satellite community.

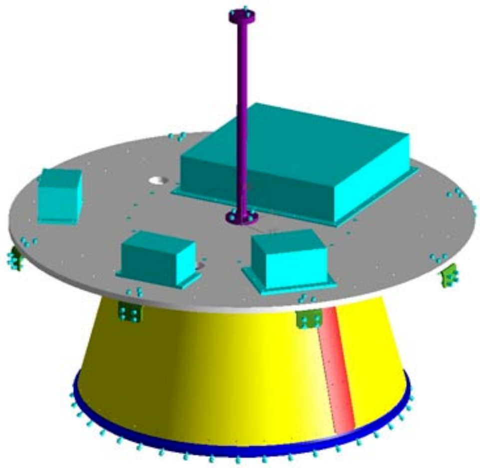

Figure 9
Starshine 3 Internal Structure

*Lightband System*

The first innovation is a non-pyrotechnic separation system that is one-fourth the weight and one-third the volume of current V-band separation systems). This advanced separation system (Figure 10), called Lightband by its developer, Planetary Systems Corporation, will impart spin to the satellite as it deploys it from the Athena payload upper deck.

Figure 10
Lightband Deployment System for Starshine 3

Since Lightband is non-pyrotechnic and the pre-load is low, shock loads at separation are low. One of the most attractive features of this system for Starshine applications is its low profile (2 1/8 in, or 9 cm, total height). This feature minimizes shadowing of the solar cells and mirrors, and it also keeps the drag configuration of the spacecraft more nearly spherical than have previous ejection systems. The derived atmospheric density data therefore will have lower scatter in this mission than heretofore.

*Power Experiments*

The second item of interest is the first flight demonstration of a cluster of Micro Integrated Power Supplies (MIPS) from NASA's Glenn Research Center. These new miniature power supplies contain rechargeable, 45mA-hr, lithium batteries, control circuitry, and monolithically integrated GaAs solar cell modules. The complete power supply fits on one square inch of circuit board . They are expected to find significant use in pico-satellites for powering sensors, serving as battery back-up for memory circuits and increasing design flexibility by having power available separate from the central bus. Five test MIPS units will fly on Starshine 3. Starshine 3 will transmit MIPS performance data to amateur radio ground stations around the world via a VHF amateur radio communication system described in the next section of this paper. Starshine 3 will also serve as a test bed for demonstrating triple-junction solar cells (Figure 11), requiring roughly half the area of

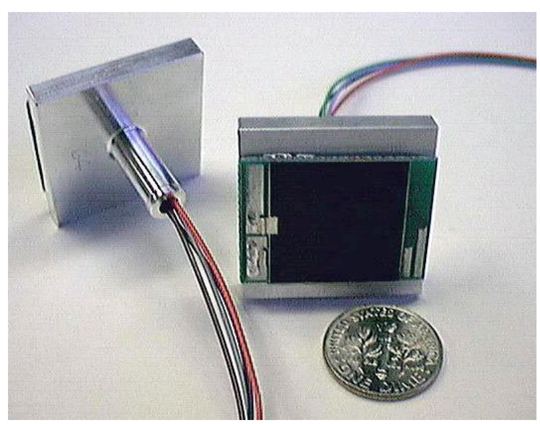

Figure 11
Triple Junction Solar Cells

conventional silicon solar cells, with much greater radiation tolerance. These cells will be the first Emcore GaInP/GaAs/Ge solar cells flown in space. For energy storage, Starshine 3 will use a lithium-ion battery consisting of three Sony 18650 cells. The storage capacity per unit mass of this battery is four times that of a conventional nickel-cadmium battery. Details of the IPS experiment and the power system are being presented in another paper at this conference.[1]

A third power related experiment on Starshine 3 will look at optically clear silicone rubber as a potential material for fabricating solar concentrator lenses. It is well known that silicone rubber will degrade in a space environment, if not protected. The degradation is primarily due to UV exposure causing the silicone to lose transparency. Starshine 3 will test two coupons of new silicone materials for their suitability as solar concentrators.

*Communication System*

One of Starshine 3 primary objectives is to involve more school children in radio science. As part of this mission, science data from experimental solar cells will be downlinked in a manner that will allow schools and radio amateurs to participate in collecting the data.

For this reason, the downlink has been designed for compatibility with the affordable Kenwood THD-7 hand held radio terminal and also for compatibility with other amateur radio terminals. The THD-7 radios contain built-in AX.25 Terminal Node Controllers (TNCs) and RS-232 ports. Consequently, they can receive Starshine 3 downlink signals directly. Schools that purchase THD-7 or similar radios will be able to receive the Starshine 3 signals with their identifying "STRSHN3 N7YTK" data header very simply. This helps the students to see that they really are receiving data from the satellite for which they polished mirrors. They will then forward the received data to the Starshine Project Internet site. This should be an excellent science and technology project for the school children.

The Starshine 3 Communications System downlink uses 9600 bps Frequency-Shift Keyed (FSK) signals at 145.825 MHz. Downlink transmissions occur at approximately one-minute intervals. (The interval can be changed by uplink to extend power-system battery life.) The Communication System parameters are given below in Table TBD.

Table I:
Starshine 3 Communications System Parameters

Characteristic
Type/Value

1. Center Frequency
145.825 MHz

2. Data Rate
9600 bps

3. Modulation
Narrowband FSK

4. Deviation
+/- 3 KHz

5. Baseband encoding
Differentially-encoded Non-Return to Zero
(NRZI)

6. Scrambling
G3RUH

7. Protocol
AX.25 packet radio -- APRS packet compatible.

8. Uplink/Downlink Multiplexing: Half Duplex

9. RF Transmit Power 1.25 watts from RF power amplifier

10. One suggested receiver
Kenwood THD-7

The Starshine 3 Communications System was derived from the SEDSAT-1 Mode L Transponder, which has been operating on orbit since 1998. Both systems were designed and built by Cynetics Corporation.

The SEDSAT Mode L Transponder is a full-duplex system (Starshine 3 is half-duplex) with redundant dual data rate L-Band uplink demodulation and a 435 MHz 9600 bps downlink.

The SEDSAT Mode-L uplink IF frequency of 139 MHz was easily adapted to the Starshine 3 uplink frequency of 145.825 MHz. Due to short schedules for the available launch, the Mode-L downlink signal frequency was simply frequency-converted to the 145.825 MHz downlink frequency. Differential encoding and decoding were added to the existing Mode-L G3RUH scrambling and descrambling.

RF Front End Protection. An RF relay protects the RF front end from near-frequency transmissions from another satellite which is ejected before Starshine 3 and which transmits immediately upon separation. Upon its own ejection from the Payload Upper Deck, a Separation Switch applies DC power to Starshine. This closes the relay and connects the antenna to the RF front end.

STARSHINE and APRS. The Amateur Position Reporting System, APRS, reports the position of Amateur Radio terminals. PC-Sat, which is being launched along with Starshine 3, will provide the first APRS service. Standard APRS uses Audio FSK (AFSK.) AFSK is a convenient hybrid modulation technique which uses FSK audio tones to in turn FM-modulate an RF carrier. This two stage modulation, "FM of FSK," is simple to implement on existing FM terminals: an audio-frequency FSK modem is added to the audio input/output of the FM transceiver.

Although it is convenient, AFSK costs approximately 9 dB in signal-to-noise ratio or in required transmitter power. Since Starshine 3 has limited available power, straight FSK has been used to save this 9 dB effective power loss. However, since the Kenwood THD-7 terminal can be used affordably to collect the Starshine data, the Starshine signal is an FSK APRS signal which the THD-7 will receive directly at 145.825 MHz.

Data Collection Participation is Encouraged. Those who have the capability of receiving Stashine 3 signals are encouraged to participate in the collection of data from the satellite. The information provided in this paper, the AX.25 protocol, and the APRS standard should be sufficient for those using terminals other than the Kenwood THD-7 to receive the Starshine downlink signals. Those using the Kenwood THD-7 will receive the signals by selecting 145.825 MHz, 9600 bps, and FSK.

## Future Plans

A request for flight assignment has been approved by NASA Headquarters for the simultaneous deployment of Starshines 4 and 5 from Hitchhiker canisters on a Space Shuttle mission in late 2002. Lightband systems will be employed on these missions. The two satellites will be externally identical to each other but their masses will be significantly different. By observing their differential orbit decay rates, it should be possible to obtain improved atmospheric density measurements. Follow-on miniature integrated power supply experiments will be flown on the satellites' outer surfaces, along with the usual complement of student mirrors.

Preliminary discussions are underway with the U.S. Air Force concerning the possibility of a flight of Starshine 6 into geosynchronous orbit on an Evolved Expendable Launch Vehicle in 2004 or 2005.


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1. Phillip Jenkins, David Scheiman, Ryne Raffelle, David Wilt, Robert Button, Mark Smith, Thomas Kerslake and Thomas Miller, "Advance Power Technology Experiment for the Starshine 3 Satellite", 15th Annual USU Small Satellite Conference, August, 2001.