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## A Novel Deployment Scheme for Solar Polar Orbits and Close-Proximity Exploration Orbits Postprint

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### Abstract

After decades of development, solar space exploration has achieved remarkable accomplishments. However, the evolution of polar magnetic fields and the inversion of solar meridional flow have been consistently constrained by projection effects, while current sheets in solar eruptions urgently require in-situ detection. Consequently, polar orbit detection departing from the ecliptic plane and close-up “touch” detection of the Sun have emerged as space missions urgently needed in the contemporary international solar physics community. Given the implementation challenges associated with polar and close-up orbits, low-cost and efficient orbital deployment solutions constitute the critical factor for successful mission execution. This paper proposes a novel scheme utilizing special asteroids for orbital insertion. Based on data from asteroid databases, we statistically analyze the orbital parameters of currently discovered high-inclination asteroids and those with perihelions approaching the Sun, and propose a piggyback asteroid mission architecture. This approach can substantially reduce satellite orbital insertion time and associated costs, while simultaneously enabling integration with asteroid exploration objectives. Should this project be realized, it would represent a significant milestone in humanity’s utilization of asteroids.

### Full Text

### Preamble

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**A Novel Scheme for Solar Polar and In-Situ Detection Orbit Deployment**

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## Abstract

After decades of development, solar space exploration has achieved remarkable progress. However, studies of polar magnetic field evolution and solar meridional flow inversion remain persistently affected by projection effects, while in-situ detection of current sheets in solar eruptions represents an urgent and demanding challenge. Consequently, polar detection from out of the ecliptic plane and close-probe detection to “touch” the Sun have become critical space projects in the international solar physics community. Given the implementation difficulties of polar and close-probe orbits, low-cost and efficient orbital deployment schemes are essential for mission success. This article proposes a novel scheme involving the use of special asteroids for orbital insertion. Based on asteroid database information, we statistically analyze the orbital parameters of currently discovered high-inclination and near-Sun asteroids and develop an approach for satellites to piggyback on them. This approach can significantly reduce satellite orbit insertion time and save costs while enabling combined asteroid exploration. If implemented, this project would represent a major step forward for humanity in utilizing asteroid resources.

**Keywords:** solar polar detection; solar close-probe detection; asteroids; orbit

## Introduction

Solar space observation began with early missions and has since included notable satellites such as Yohkoh, SOHO, TRACE, Ulysses, RHESSI, Hinode, STEREO, and SDO. These spacecraft, equipped with various instruments for multi-wavelength imaging and in-situ detection, have greatly advanced our understanding of solar eruption processes and physical mechanisms. However, most operate in Earth-centered orbits, which fundamentally limits observations of the solar polar regions. Ulysses remains the only satellite to have left Earth orbit and entered a solar polar orbit, though it carried no imaging instruments and observed from a single line-of-sight direction near the ecliptic plane.

Solar polar regions are critical for understanding solar activity and magnetic field variations. Through dedicated polar observations, we can better comprehend the periodic variations of solar activity, properties of the solar wind, and evolution of solar magnetic fields. Solar atmospheric activities exhibit extremely complex three-dimensional structures, and single line-of-sight magnetic field observations suffer from inherent limitations. Theoretical and numerical simulation studies have progressed toward more realistic three-dimensional models, all of which urgently require multi-perspective stereoscopic observations to probe these three-dimensional structures and accurately grasp the underlying physical processes. The energy for solar activity originates from the sudden release of

magnetic free energy, with magnetic reconnection playing a central role. Current understanding of magnetic reconnection mechanisms remains limited, partly due to the lack of in-situ detection of current sheet structures produced during reconnection. This requires satellites to approach within a few solar radii, crossing current sheet structures to directly detect plasma properties within them. Close-probe detection can also provide unprecedented ultra-high-resolution images of solar activities, helping to solve long-standing mysteries.

Deep space exploration of the Sun, including polar orbit detection and close-probe detection of current sheets and fine structures of solar activities, has become an urgent priority. China's deep space exploration technology has overcome challenges posed by Sun-Earth distances, and Chinese solar physicists have proposed their own SPO and Solar Probe plans, with key technology research already underway.

## Orbital Deployment Challenges and Traditional Approaches

Deploying satellites directly into deep space is extremely difficult, requiring far more energy than any current rocket can provide. The few solar detection satellites launched internationally that deviate from the ecliptic plane have all relied on planetary gravity assists. For example, the first solar polar orbit satellite Ulysses, launched in 1990, required 16 months to reach Jupiter, where Jupiter's powerful gravity deflected its orbit to achieve an  $80.2^\circ$  inclination, entering a 6-year solar polar orbit. The Solar Orbiter (SolO) mission, launched in 2020, uses Earth and Venus gravity assists to achieve a  $24^\circ$  inclination with a perihelion of 0.28 AU. The Parker Solar Probe (PSP), launched in 2018, uses Venus gravity assists to approach within 0.05 AU of the Sun's surface. STEREO's two satellites used lunar gravity assists to enter heliocentric orbits.

Solar sails have also been proposed as an alternative. A solar sail typically consists of a large membrane that deploys after launch, using solar radiation pressure for propulsion. Although solar sails provide small thrust, they can operate continuously. This concept was proposed over 20 years ago, but major difficulties lie in manufacturing: solar sails require thin, highly transparent, high-strength materials with sufficiently large area, plus precise control systems. Japan's IKAROS mission in 2010 successfully demonstrated solar sail technology, but the low thrust means orbit raising requires extremely long periods.

## The Asteroid Piggyback Scheme

Asteroids are small celestial bodies orbiting the Sun, typically composed of rock, metal, or ice, without atmospheres, and with irregular shapes ranging from meters to hundreds of kilometers. According to Lowell Observatory data, over one million asteroids have been observed, most located in the main asteroid belt between Mars and Jupiter (2-4 AU). Asteroids are among the oldest objects

in the solar system, preserving important information about solar system formation and evolution. They contain rare minerals that could become targets for future space mining, and some near-Earth asteroids pose potential impact hazards, leading to planetary defense programs like NASA's DART mission in 2022, which successfully altered an asteroid's orbit through impact.

This article proposes a novel deployment scheme for solar polar and close-probe orbits that can significantly save time and economic costs: piggybacking on special asteroids to directly insert satellites into target orbits while also enabling asteroid resource utilization. To achieve scientific objectives, solar polar orbit satellites require inclinations of at least  $60^\circ$ . We statistically analyzed asteroid orbital parameters from current databases to identify suitable candidates.

## Statistical Analysis of Asteroid Orbits

Figure 1 shows the distribution of asteroid orbital inclinations and semi-major axes. The number of asteroids decreases with increasing inclination, though some exist with inclinations greater than  $60^\circ$ . Most have low eccentricities (0-0.1), with some having very circular orbits. Near Earth orbit, there exist asteroids with relatively high inclinations and low eccentricities that can meet solar polar satellite piggyback requirements.

For close-probe detection requirements, we analyzed asteroid perihelion distance distribution (Figure 3). The number of asteroids increases with perihelion distance. The asteroid with smallest perihelion is 2005 HC4 at 0.55 AU (about 200 solar radii), and some asteroids exist within 0.1 AU.

Some asteroids have both high inclination and small perihelion distance, simultaneously meeting polar and close-probe requirements. Figure 4 shows a scatter plot of asteroids with inclination  $>60^\circ$  and perihelion  $<0.5$  AU, totaling 11 such objects. Due to their small size, most asteroids in databases lack diameter measurements. Among high-inclination asteroids, only 7 have measured diameters, typically tens of kilometers. With improving observational capabilities, smaller asteroids will be discovered.

## Implementation Scheme and Candidate Asteroids

Based on asteroid statistics, we propose a satellite-asteroid piggyback scheme. The implementation involves installing a capture frame at the satellite's front, similar to a solar sail but made of highly elastic and tough material to net the asteroid. The frame diameter must exceed the asteroid diameter. After selecting an appropriate target asteroid through precision orbit determination (with positional measurement accuracy reaching 50-100 milliarcseconds), the satellite is launched into a near-Earth heliocentric orbit. Through autonomous navigation and mutual approach techniques, the satellite intersects the asteroid's orbit at the crossing point. The asteroid passes through the capture frame, pulling the satellite into its orbit via elastic net tension. After insertion, the

satellite detaches and adjusts attitude to enter operational mode. This shortens insertion time to 2-5 years compared to planetary gravity assist schemes.

Figure 5 shows candidate asteroid orbits, with Mercury, Venus, and Earth orbits shown in pink, lavender, and dark blue respectively. The gray orbit shows asteroid 2003 QQ47 with  $62.19^\circ$  inclination, 1.09 AU semi-major axis, 0.19 eccentricity, and 24.5 km/s orbital speed. During encounter, the asteroid pulls the satellite into its orbit through the elastic net.

Assuming equal speeds, the momentum change is  $I = mva - mvs = mv$ , where  $va$  and  $vs$  are velocity vectors and  $m$  is satellite mass. According to the impulse theorem  $I = Ft$ , for a  $60^\circ$  angle and using China's ASO-S satellite mass of 859 kg, if net action time is 2 seconds, the average tension is about  $2 \times 10$  [units]. The instantaneous force is enormous, posing material challenges. Increasing action time through elasticity can reduce tension. More refined analysis shows elastic tension increasing gradually from zero to maximum while the satellite accelerates, requiring a mechanism to detach from the net at the appropriate moment.

For inclinations  $>60^\circ$ , there are currently 11 known asteroids within 1.1 AU. If the requirement is relaxed to  $>30^\circ$ , hundreds of candidates exist. For close-probe detection, the challenge is lower. Due to net size limits, asteroid diameters should preferably be  $<100\text{m}$ . Discovery rates of 50-140m, 20-50m, and 10-20m near-Earth asteroids are increasing annually.

## Advantages and Challenges

This concept, first proposed by our team, combines solar deep space exploration with asteroid exploration. Compared to SolO's  $24^\circ$  inclination and 0.28 AU perihelion, our scheme provides near-circular orbits with  $\sim 60^\circ$  inclination, more advantageous for polar detection. Some orbits enable both polar and close-probe detection. Insertion time is 2-5 years, shorter than planetary gravity assist or solar sail schemes. The scheme is flexible—if encounter fails, the satellite can continue its original mission, and asteroids can be reused. It also provides experience for hazardous asteroid deflection without introducing new threats to Earth.

Key challenges include: (1) Elastic net material and manufacturing—requiring high toughness, light weight, and precision deployment from limited volume; (2) Precise orbit measurement and control for both asteroid and satellite; (3) Satellite and payload must withstand extreme impact forces; (4) Autonomous attitude adjustment after violent impact.

## Mission Implementation

We recommend phased implementation: (1) Launch an experimental microsatellite for scheme validation; (2) Launch close-probe detection satellite; (3) Launch polar orbit detection satellite.

## Conclusion

Solar deep space exploration has been pursued for years, but few projects have been implemented due to technical difficulties and costs. Our statistical analysis reveals a “stereoscopic transportation system” of diverse asteroids in the solar system. The proposed piggyback scheme can significantly reduce mission time and fuel costs, advancing both solar physics research and asteroid resource utilization. Successful implementation would elevate China’s solar physics research to international leadership while driving developments in satellite measurement/control and materials science, and representing the first utilization of asteroid resources.

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### A Novel Scheme of Orbit Deployment for Polar and In-Situ Detection of the Sun

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**Abstract:** After decades of development, significant progress has been made in the field of space exploration of the Sun. However, studies on the evolution of polar magnetic fields and the inversion of solar meridional flows have been persistently affected by projection effects. Additionally, the in-situ detection of current sheets in solar eruptions remains an urgent and demanding task. Consequently, polar detection from out of the ecliptic plane and closer detection to “touch” the Sun have become urgent space projects in the international solar communities. However, implementing polar and closer detection orbits presents several challenges, making low-cost and efficient orbital deployment schemes essential to the successful execution of the mission. In this article, we propose a novel scheme involving the use of some special asteroids for orbital insertion. We analyze the orbital parameters of high-inclination and near-Sun asteroids in the asteroid database and develop an approach for satellites to take on them. Following this approach, the time for satellites to get into orbit can be significantly reduced and costs can be greatly saved, while it can be combined with the asteroid exploration. If implemented, this project would also represent a significant step forward for humans in utilizing the resources of asteroids.

**Keywords:** polar detection of the Sun; in-situ detection of the Sun; asteroids; orbit

*Note: Figure translations are in progress. See original paper for figures.*

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