ARTIFICIAL LAGRANGE ORBITS FOR CONTINUOUS POLAR OBSERVATIONS

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Abstract
Solar sails are being developed by NASA, the Japan Aerospace Exploration Agency, the European Union, and private space organizations to enable new space science and exploration missions. This new technology can be used to create Artificial Lagrange Orbits above the earth's Polar Regions to provide continuous full-disk monitoring from a unique vantage point.

ALO's ADDRESS KEY CHALLENGES FOR EARTH SYSTEM SCIENCE

The community requires continuous full-disk, polar-centered measurements of the earth to monitor the polar ice caps and gain a continuous synoptic view of the interaction between large weather systems in the Polar Regions and those in the mid latitudes. Such polar-centered measurements are needed to complete the whole system picture of our planet without partitions and improve understanding of the interactions along zonal and vertical boundaries. These measurements would enable the benefits of current geostationary satellite orbits, including rapid scan operations, feature tracking, and atmospheric motion vectors (or cloud drift winds), which are currently enjoyed only by satellite orbits in the middle and tropical latitudes. Including UV light (340 and 388 nm), visible light, and NIR channels (>1 micron) in these observations would allow the study of ice features and ice/cloud discrimination. These channels would also enable monitoring of Antarctic ice margins and ozone measurements, including the use of ozone observations to map out high altitude (20 km) winds where most of the interactions between the stratosphere and troposphere tend to occur.

To make these measurements, the observing platform needs to be elevated out of the plane of Earth's orbit (ecliptic) in Artificial Lagrange Orbits (ALOs). Maintaining these orbits requires advanced propulsion with low thrust and high efficiency for the very large delta-v needed. Solar sails are the most efficient long-term solution to this problem [1, 2].

TECHNOLOGIES REQUIRED TO ENABLE ALOs ARE RAPIDLY MATURING

Two recent developments reinforce the timeliness and advantages of continuous full-polar hemispheric remote sensing. The DSCOVR mission, launched in February 2015, entered orbit around the first Lagrange point between the sun and Earth in June of 2015. Project science teams are analyzing DSCOVR's 10-channel earth imagery and radiation budget measurements. Science results will begin to be available over the next year. These measurements will provide supporting evidence for the advantages of the full-disk monitoring approach, albeit with the disk centered on the equator instead of the poles.

NASA is developing the propulsion technology (solar sails) to enable these orbits with the planned flight of Near Earth Asteroid Scout (NEA Scout) mission in 2018 [3]. This technology is strongly supported in the White House Office of Science and Technology Policy (OSTP) Strategic and Action Plans released on October 28th (see Goal 5 of Space Weather Action Plan) [4].

ALOs are needed to increase the warning time for geomagnetic storms by placing the space platform closer to the sun than L1, where these measurements are currently taken. Although these plans are directed toward improving space weather observations, the basic technology and performance level can support the out-of-plane orbits discussed in this paper. The earth science community should strongly support near-term development and testing of this technology. To achieve this end, partnerships should be sought with other interested communities, including

NASA, the Heliophysics community, NOAA, the USAF, and international partners.

WHY SPACE-BASED OBSERVATIONS?

Continuous monitoring of large-scale (regional) features cannot be accomplished from the ground. Unlike any other observational platform, ALOs enable a unique monitoring of the radiative balance of both the diurnal and seasonal cycles under quasi-stationary – or at least slowly varying – illumination-observation angles. This will be a tremendous advantage for improving detailed definitions of surface features, e.g., Bidirectional Reflectance Distribution Function (BRDF), essential for correct interpretation of trends in land use, deforestation, and afforestation. Observation of the surface during entire daily cycles provides the information necessary to separate different effects due to shadows, surface types, and land use. This is extremely important for planners and managers to evaluate and compare local experiences against high resolution earth resources observations from low Earth orbits (LEOs).

Another advantage ALOs offer is continuously monitoring Polar Region transport and deposition processes of pollutants, carbon particles from forest fires, and volcanic explosive events. Soot and organic carbon depositions are a key factor in the thinning of the ice caps. Melting ice affects ocean thermohaline circulation with consequences on fisheries and related human activities.

Basic science progress will accelerate with direct access to large-scale phenomena suitable for framing issues and validating calibration of other environmental observations. It will be possible to place local-scale observations of weather and environmental parameter changes in the larger context of regional studies. Likewise, limited temporal studies will benefit from the long-term observations taken by instruments on platforms that are subject to minimal thermal fluctuations and possess better long-term stability. Ultimately, both climate science and weather predictions will benefit from accessing global views of the Polar Regions at high refresh rate with a minimal processing overhead.

SOLAR SAILS

Solar sail propulsion uses sunlight to propel vehicles through space by reflecting solar photons from a large mirror-like sail made of a lightweight, highly reflective material. The continuous photonic pressure provides propellantless thrust to perform a wide range of advanced maneuvers, such as hovering indefinitely at points in space or conducting orbital plane changes more efficiently than conventional chemical propulsion.

Practical concepts for solar sailing have existed for approximately 100 years, beginning with Tsiolkovsky and Tsander in the 1920s. A team at JPL completed the first serious mission study in the late 1970s for a rendezvous with Halley's Comet [5]. An effort by McInnes in the 1990s and the publication of his PhD dissertation as a textbook on solar sailing helped reinvigorate interest in solar sailing as a research topic [1]. In the early to mid 2000's, NASA's In-Space Propulsion Technology Project made substantial progress in the development of solar sail propulsion systems. Engineers produced and successfully tested two different 20 m solar sail systems in the Glenn Research Center's (GRC's) Space Power Facility at Plum Brook Station, Ohio [6].

Outside of NASA, solar sailing has been tested in space. In the summer of 2010, the Japanese Aerospace Exploration Agency (JAXA) launched a solar sail spacecraft named IKAROS in tandem with another mission to Venus. The sailcraft IKAROS (14 m^2) is the first in-flight demonstration of solar sailing [7]. Figure 1 is a photograph of the IKAROS spacecraft and deployed solar sail in interplanetary space. While the effects of solar radiation pressure (SRP) are smaller on this sailcraft as compared to other concepts for solar sails, the design achieved numerous program objectives, including verifying SRP effects on the sail and performing in-flight guidance and navigation techniques. The University of Surrey is developing multiple CubeSat-class solar and drag sail spacecraft, including CubeSail, DeorbitSail, and InflateSail. Each will have a total mass of around 3 kg and will deploy 16 m^2 sails in LEO.

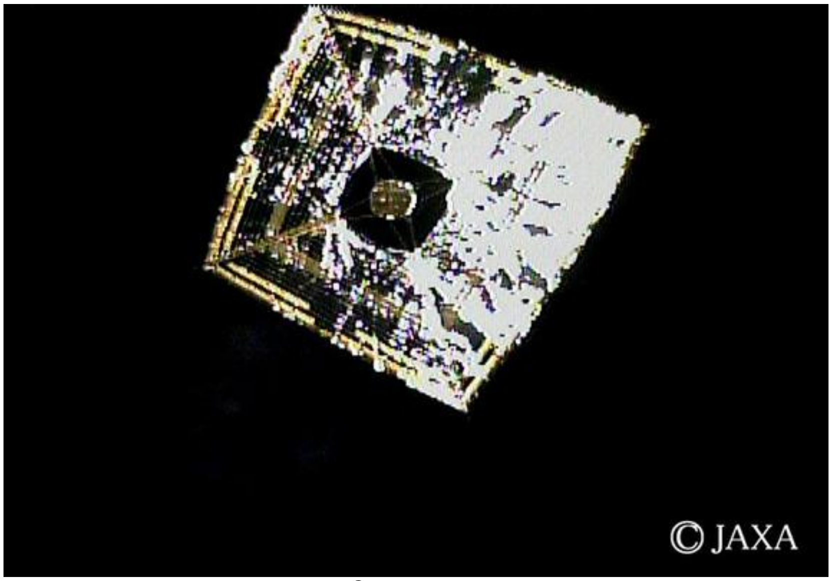

Figure 1. The Japanese flew the IKAROS 196 m^2 solar sail into interplanetary space in 2010, demonstrating the technology for future mission implementation. (Image courtesy of JAXA.)

The NEA Scout mission, managed by the NASA Marshall Space Flight Center (MSFC), will use an 86 m^2 sail as primary propulsion while surveying and imaging one or more NEAs of interest for possible future human exploration. Manifested for flight in 2018, NEA Scout will be NASA’s first interplanetary solar sail mission. The Planetary Society's Lightsail-A (5.65 m^2), flew successfully in Earth orbit in the spring of 2015. LightSail-B is manifested for launch in the fall of 2016.

Due to the continuous force provided by solar radiation pressure on a solar sail, solar sail spacecraft can fly in non-Keplerian orbits, such as ALOs, and can continually maneuver throughout flight without the use of finite propellant – providing a long-term capability for sustained scientific observations of Earth’s Polar Regions.

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