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LARGE MORPHING SPACECRAFT FOR FLEXIBLE SCIENCE MISSIONS

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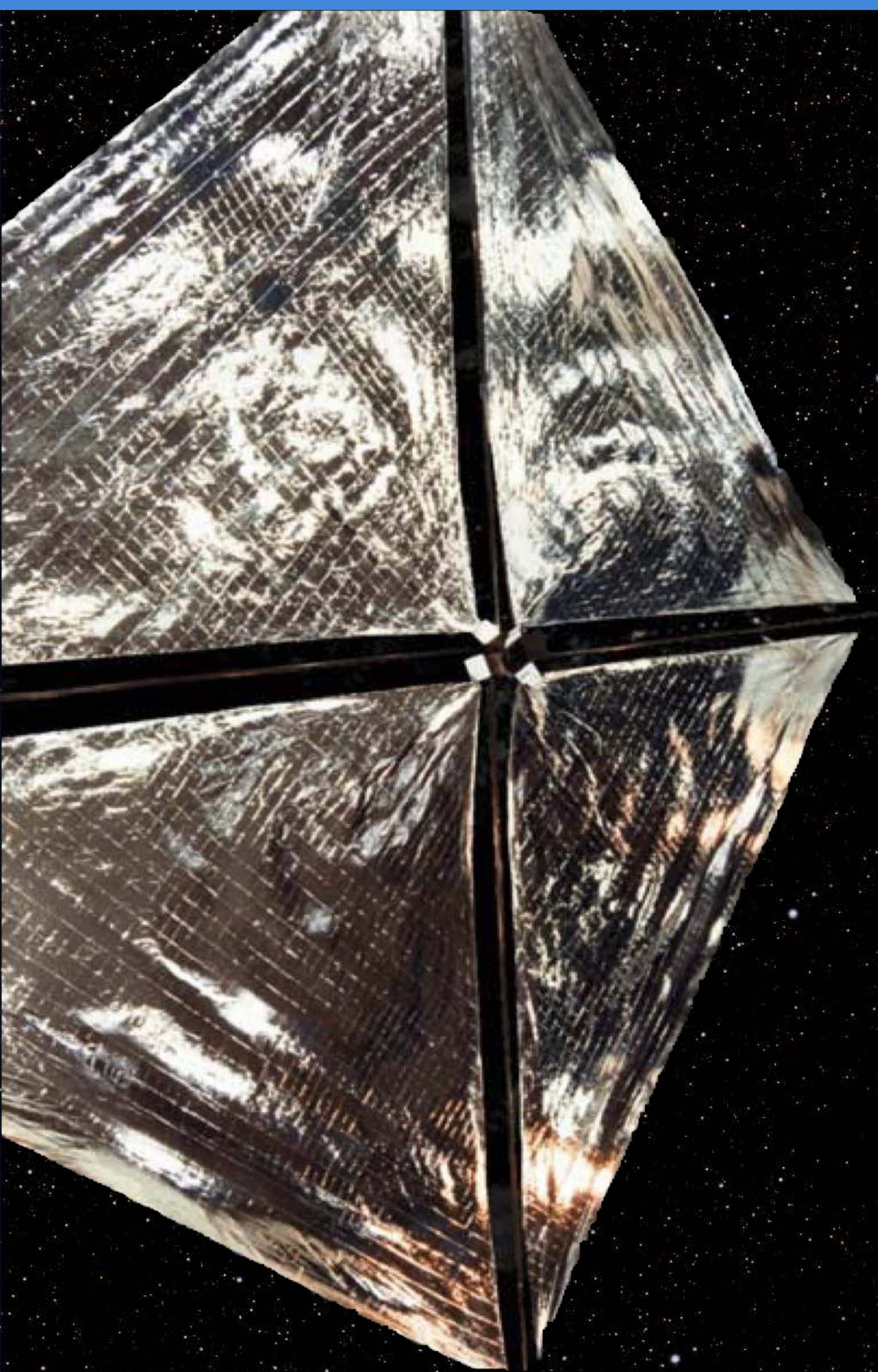


Sailships in Space

Solar sail technology offers a new capability to enable fast, efficient and low cost science missions throughout the Solar system. Uniquely, solar sails exploit the flux of momentum transported by solar photons to generate a thrust force and thus do not rely on a propellant like conventional, chemical and electric thrusters. The mission duration is therefore only limited by the lifetime of the onboard subsystems and the integrity of the lightweight sail membrane. This makes a solar sail the ideal candidate for a wide range of space missions, including space weather forecasting and exploration of asteroids. However, the thrust from solar radiation pressure is limited to be always directed away from the Sun, and its magnitude follows an inverse square law with solar distance, making the sail less efficient at large distances from the Sun.

A Multi-functional Platform

In order to increase the range of potential mission applications, we are investigating future reconfigurable spacecraft able to change their shape during the mission. It is envisaged to use the membrane of a solar sail as a multi-functional platform that can deliver additional key mission functions such as power collection, sensing, communications and a more flexible thrust control.

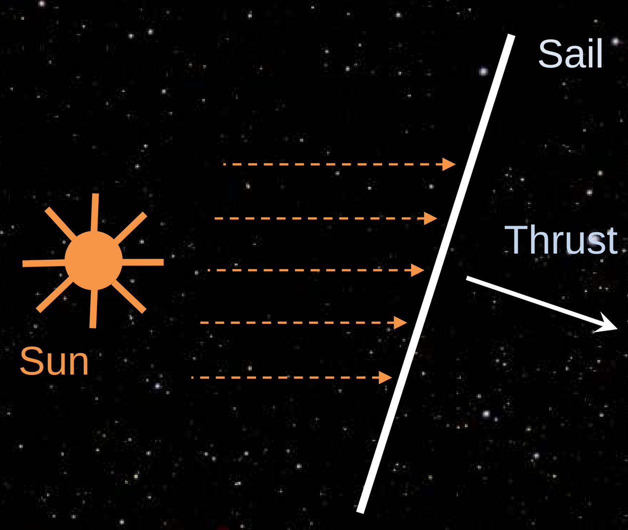


Fig. 1 Flat sail in thrust mode

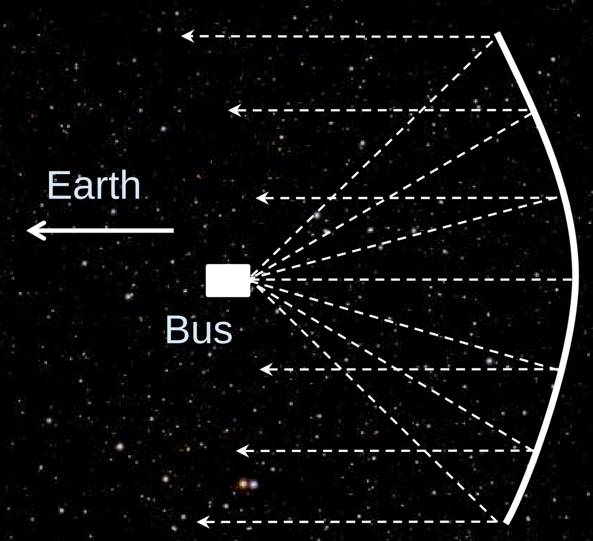


Fig. 2 Parabolic sail in antenna mode

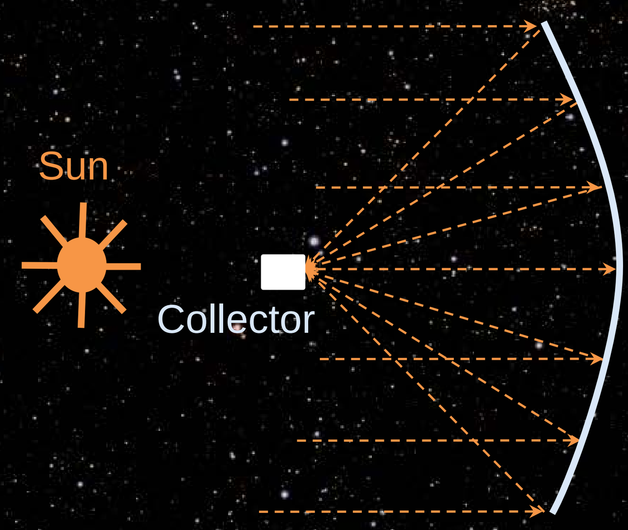


Fig. 3 Parabolic sail in power collection mode

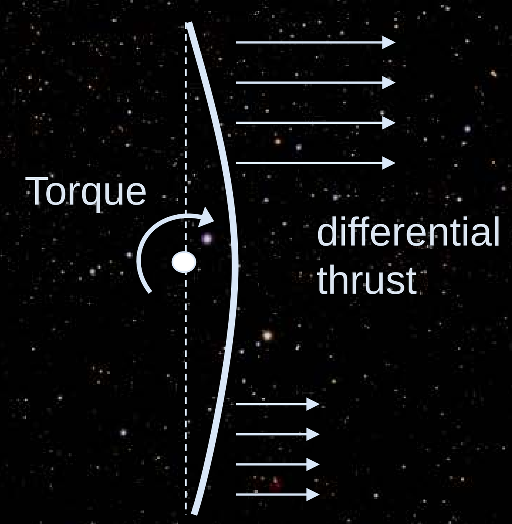
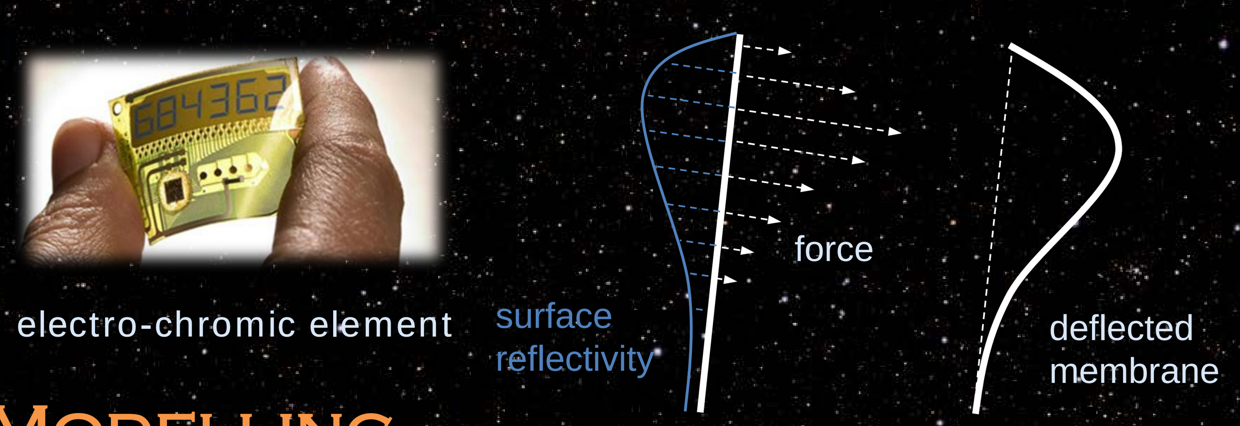


Fig. 4 Sail in attitude control mode

Morphing Solar Sails

To this aim, we are introducing concepts of shape change and continuously variable optical properties to large gossamer (lightweight) spacecraft. The dynamics of a flexible sail membrane with a variable surface reflectivity distribution are investigated, which can be achieved through the use of electro-chromic coatings. These consist of an electro-active material that changes its surface reflectivity according to an applied electric charge.



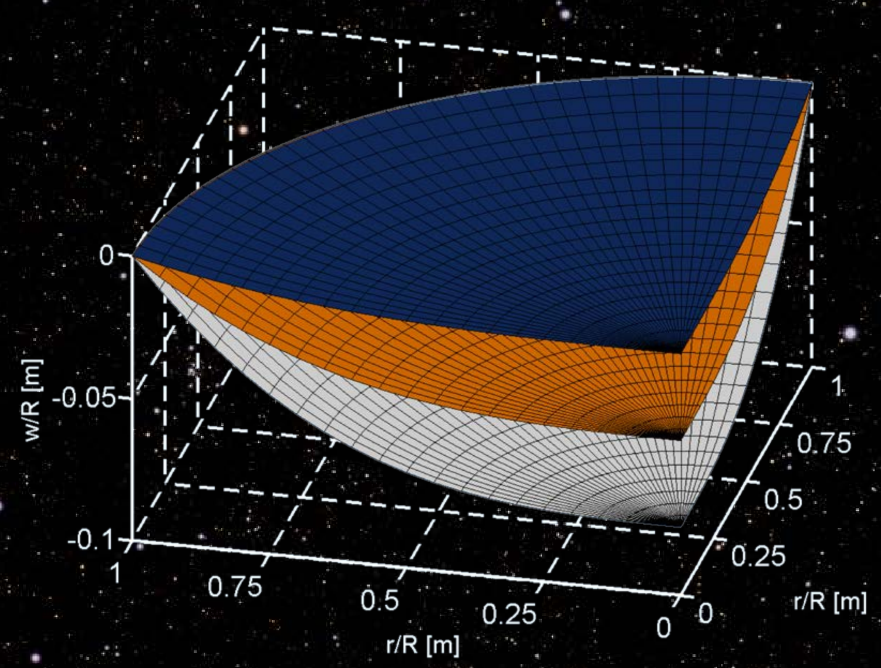
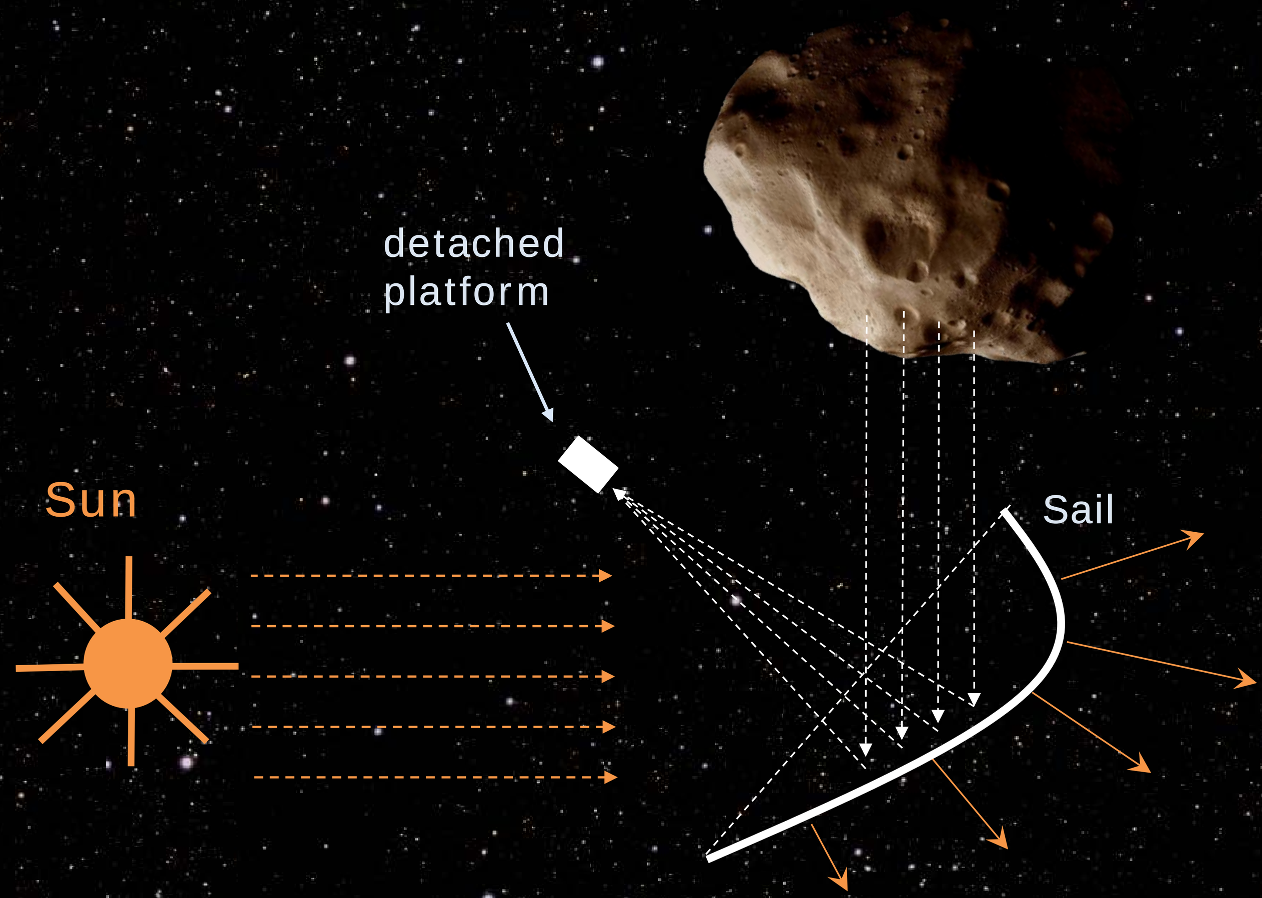


Fig. 5 Deflected shapes of a circular sail membrane (radius $R = 100$ m) with uniform light pressure distribution and for different surface reflectivities $\rho = 20$ % (blue), 60 % (orange) and 100% (white). Plot limited to one quarter of total sail area

Modelling

The sail membrane is modelled as a single surface framed by a simply supporting rigid boom structure. When changing the reflectivity coefficient across the sail membrane, the forces and torques acting on the sail can be controlled without changing the incidence angle relative to the Sun. In addition, by assigning an appropriate reflectivity function across the sail, the load distribution due to solar radiation pressure can also be manipulated to control the billowing of the membrane. By an appropriate choice of spatial reflectivity across the membrane, specific geometries can be generated (see Fig. 5), such as a parabolic reflector, thus enabling a multi-functional sail.



Applications

For example, the sail may start at Earth escape in a flat configuration heading towards a designated small body like an asteroid or comet, for a science mission. In close proximity to the target body, the sail reconfigures to a parabolic shape, using its membrane as a remote sensing device or as a large-aperture communication antenna, before continuing again in a flat thrust mode. Detached platforms are positioned in the focal point of the parabolic membrane, formation-flying with the solar sail, to acquire data from the asteroid surface and further sending it back to Earth for examination.

Conclusions

Future morphing solar sails can use distributed electro-chromic elements across the membrane to apply shape changes during the mission. This novel concept of optical reconfiguration can potentially extend solar sail mission applications and further enable flexible thrust vector control without using moving attitude control devices. Further project steps will also consider segmented sail panels connected by hinges that are easier to be deployed and controlled within the space environment. Additional opportunities exist in the use of the large available solar sail area for distributed payloads such as a phased array to generate a high-gain antenna.

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