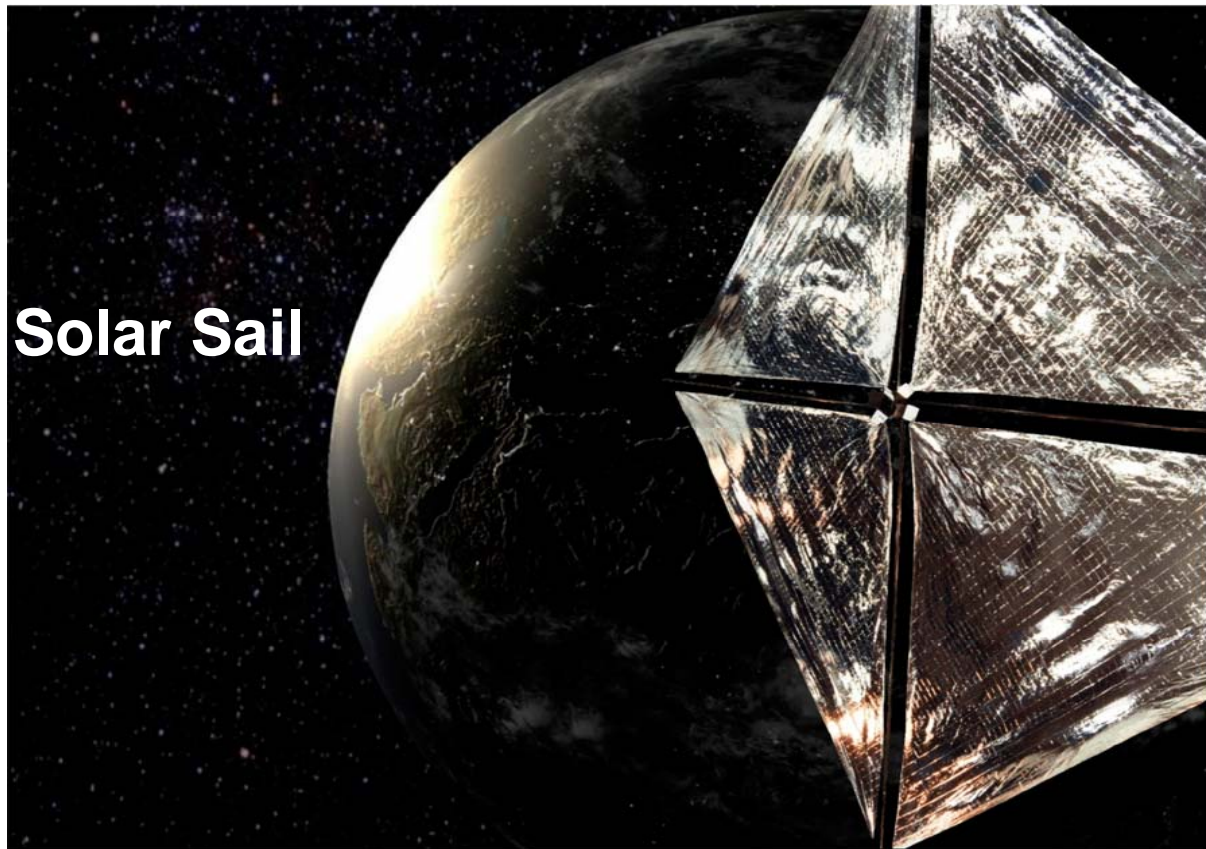




The European Solar Sail Technology Status





The European Solar Sail Technology Status

- Solar Sail means: to sail with the photon stream of the Sun – not in solar wind (1000/1!)
- The range of thrust provided by solid and liquid rockets is on the order of 5 to 5,000,000 N.
- Cold gas system, which uses an inert gas stored at a high pressure as propellant create thrust from about 0.05 to 200 N - but they are the heaviest systems available with respect to their performance capabilities.
- The thrust created by electrical propulsion systems is relatively small also, however, being on the same level as cold gas systems.
- At best case a **solar sail** will receive only force of 9 N/km² located in Earth orbit and the sail ship is slowly but continuously accelerated to accomplish a wide-range of potential missions.
- These propulsion technology systems eventually could lead to missions to study the Sun and its heliosphere - the magnetized bubble of plasma around the Sun - that are impossible using today's technology
- After successful deployment test on ground in 1998 an ESA/DLR-Project was planned:
Solar Sail 2003: 20x20 m only Deployment Demonstrator, 2004: 50x50 m Sailing Ship, 2006: 100x100 m Sailing Ship & Payload
- Status now:
 - Phase B for Deployment Demonstrator successful completed in 2004 – but up to now no funding for phase C/D.
 - Study phase for a new mission “GEOSAIL” in cooperation with KT as prime contractor for ESA was started in 11/2006.



The European Solar Sail Technology Status

Solar Sail/Basics

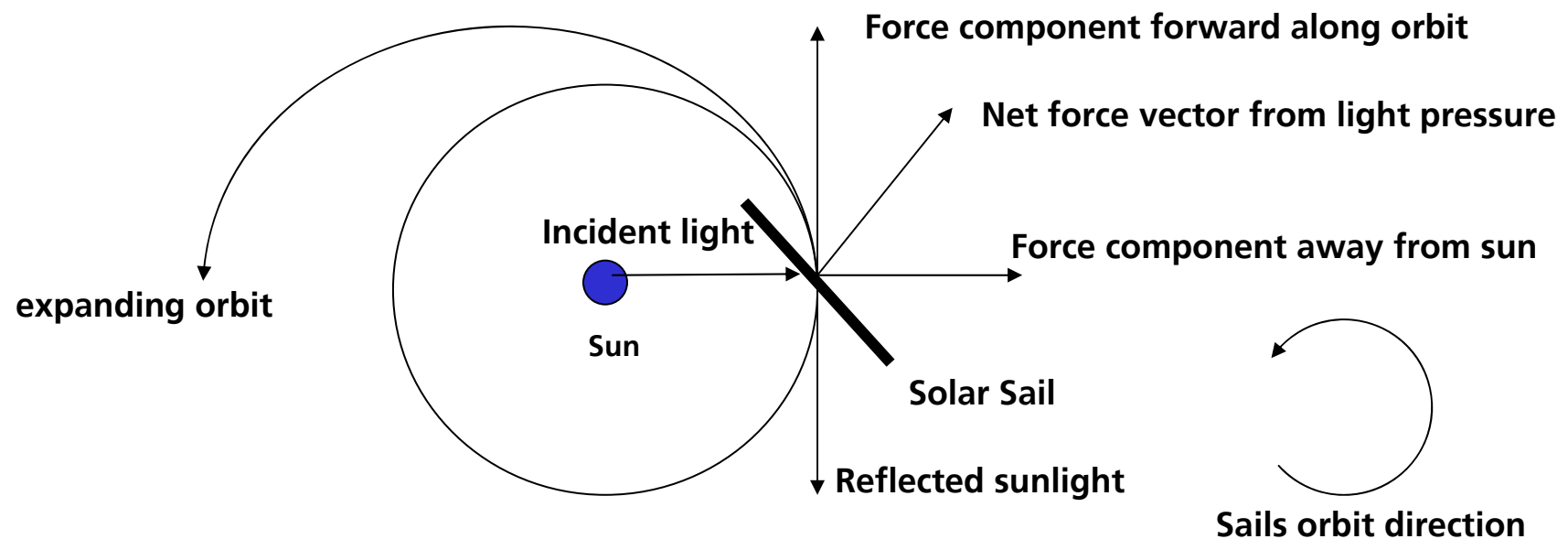
- Required minimum acceleration as defined for sailing: in the range 0,1 to 1 mm s⁻²
- Because permanent available, increase of velocity per year up to 31,5 km s⁻¹!!!
- As result it would be possible to realize a transfer Earth to Mars within ca 400 days (correspond to transfer time for chemical propulsion)
- Problem: Acceleration for a solar sail is inverted to its mass:
State of the art: 7,5 μm foils with $\sigma_{\text{sail}} = 5,5 \text{ g m}^{-2}$ is available and space proofed (would have max. 1,53 mm s⁻² acceleration (sail ship, without payload!))
- To ensure a required minimum acceleration of 1 mm s⁻² for the system, only 2,8 g payload pro m² are permissible
- For typical 100 kg (payload + service unit) a 35000 m² sail is required. That means square with approx. 190 m basis length!
- But because theoretical reasons, even for sail foils with $\sigma_{\text{sail}} = 0$, for 1AU no more payload than 8,3 g m⁻² is possible!!!

$$\sigma_{\text{payload}} = (1 + r) \frac{I_0}{c \cdot a_{\text{min}}} - \sigma_{\text{sail}}$$

The European Solar Sail Technology Status

Solar Sail/Basics

- Because orbit-mechanical reasons only two orbit maneuvers are possible:
orbit expanding and **orbit shrinking**
- Orbit expanding

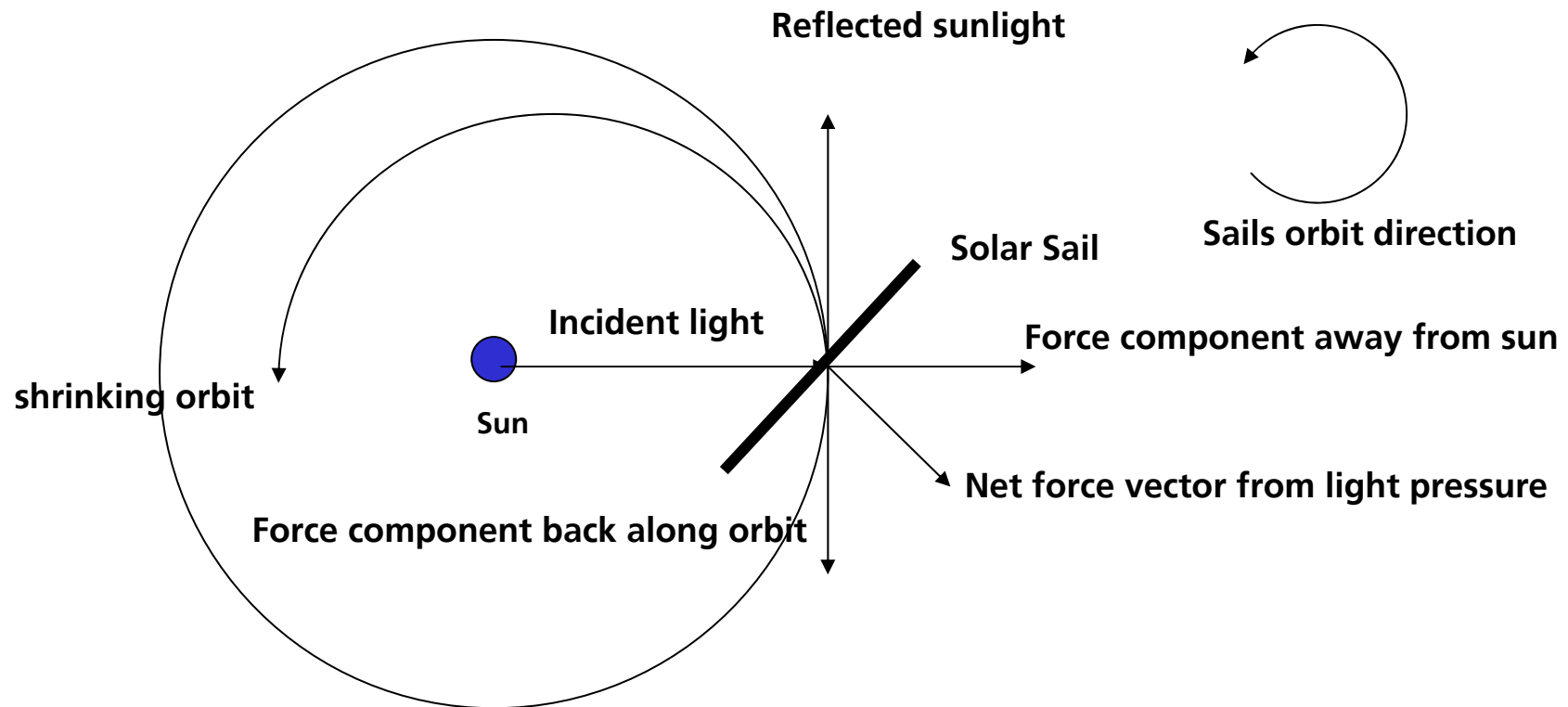




The European Solar Sail Technology Status

Solar Sail/Basics

➤ Orbit shrinking

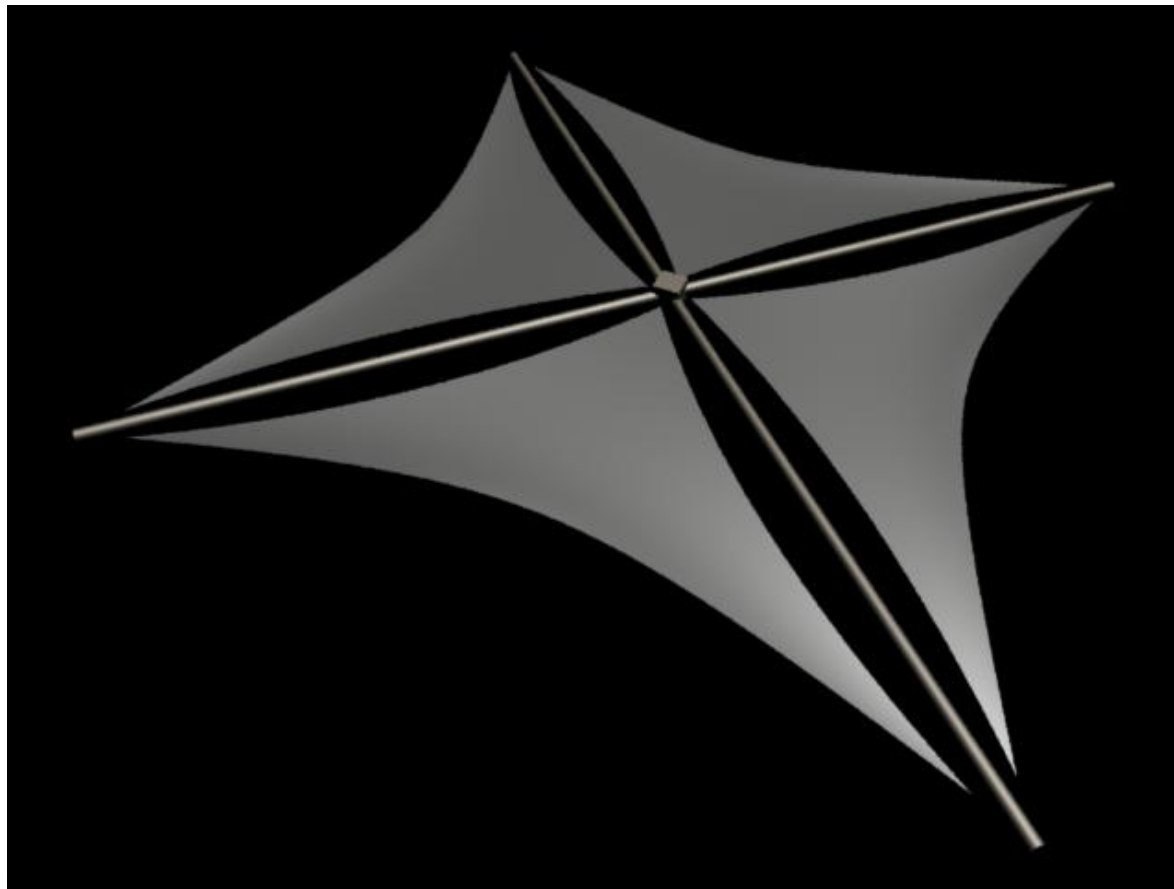




The European Solar Sail Technology Status

Solar Sail/Configurations

- Deployed by Booms solidly build and stiffly

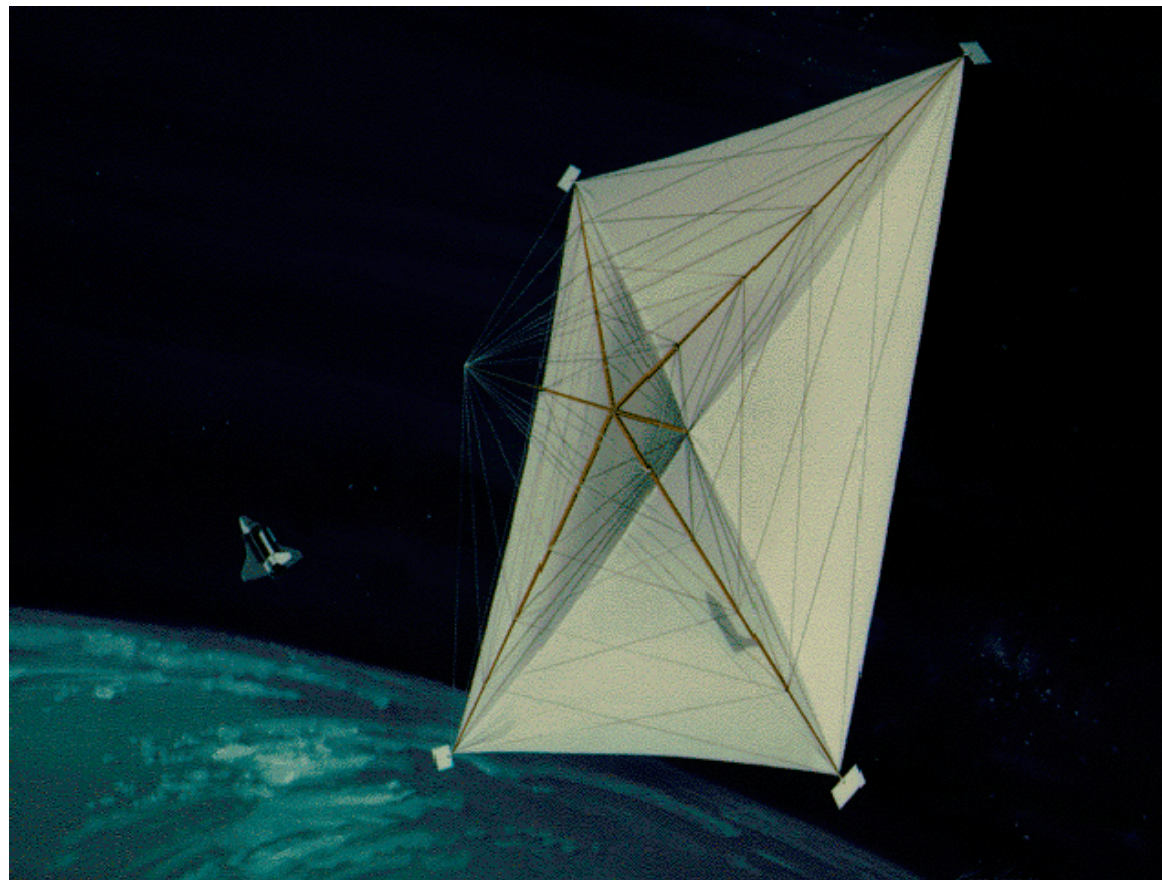




The European Solar Sail Technology Status

Solar Sail/Configurations

- Deployed by Booms and stabilized by tensions

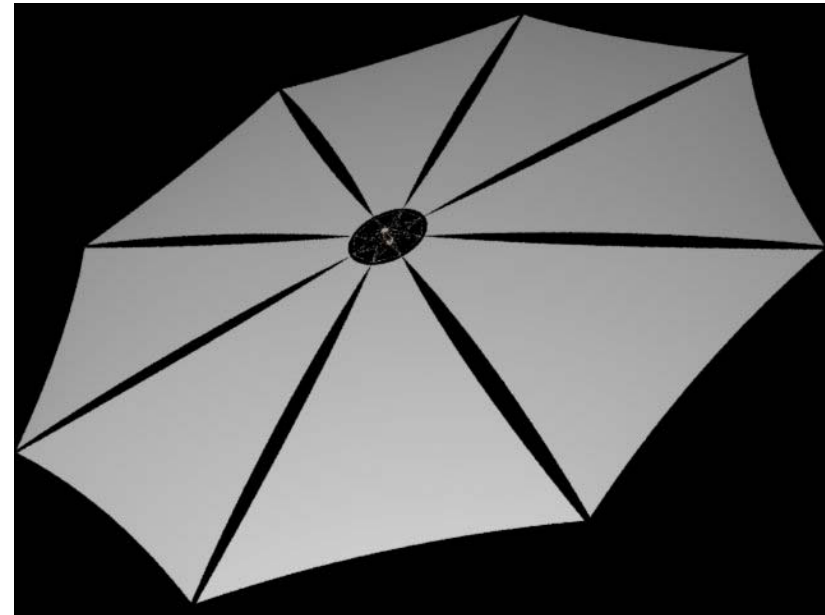
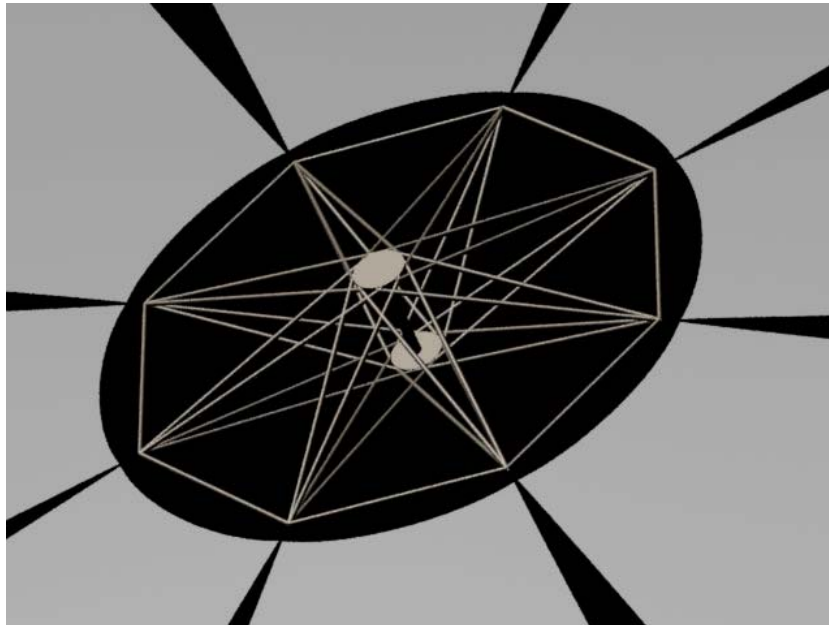




The European Solar Sail Technology Status

Solar Sail/Configurations

- Sails by centrifugal force deployed and stabilized (Gyro-Typ)

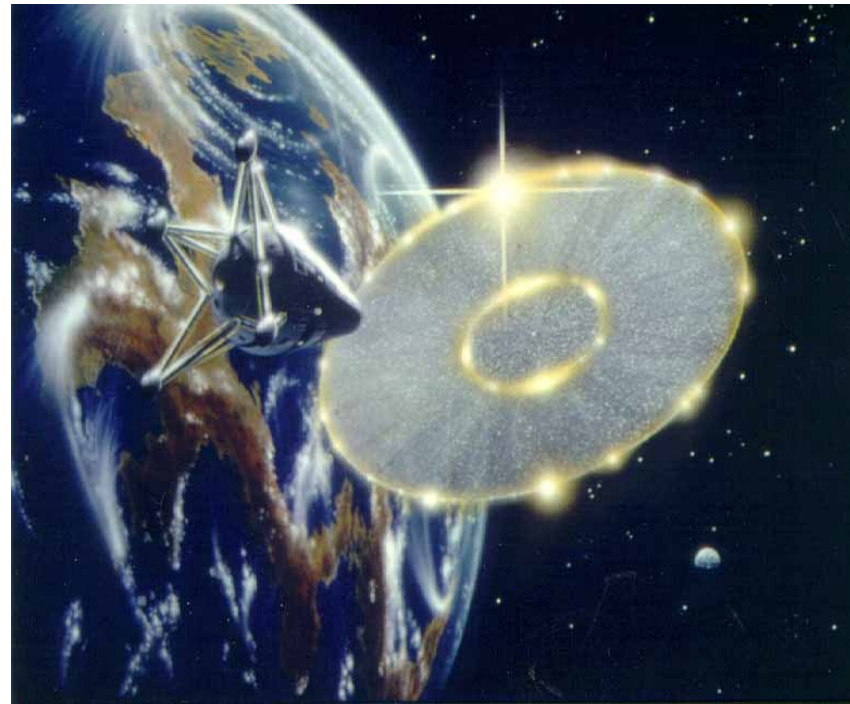




The European Solar Sail Technology Status

Solar Sail/Configurations

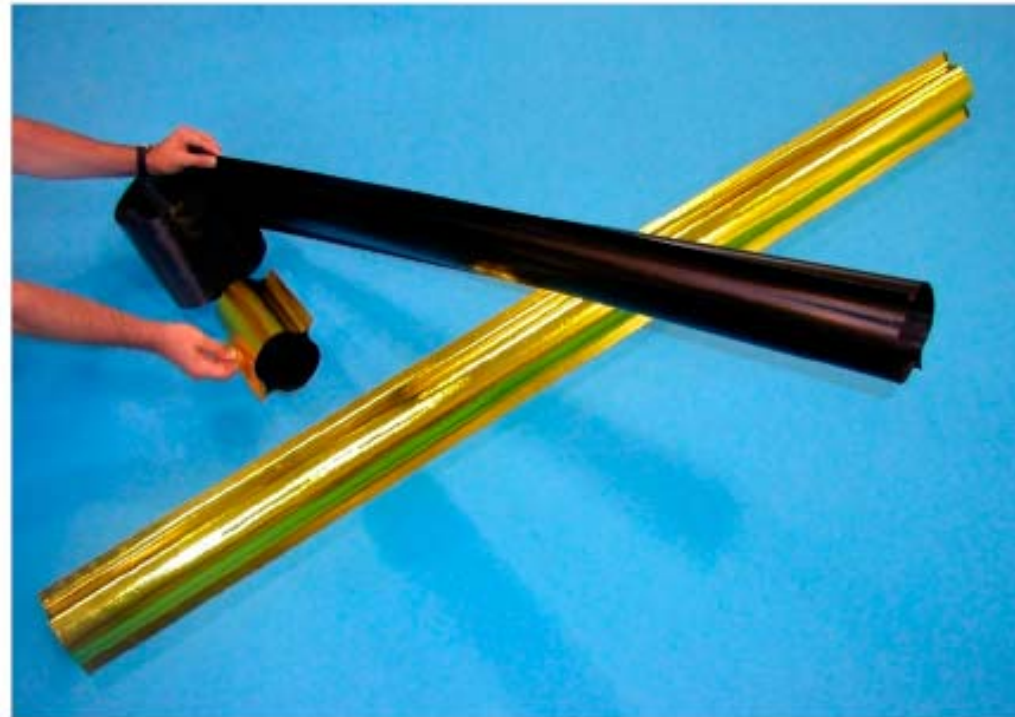
- Sails by an outer ring deployed and stabilized (Torus -Typ)



The European Solar Sail Technology Status

PROGRESS IN DEPLOYABLE BOOMS (by DLR)

- Ultra light seam bonded STEMs (storable extendible tubular masts) made of carbon composite materials have been selected as technical baseline for the deployable support structure, developed and manufactured by DLR Institute of Composite Structures and Adaptive Systems
- Composite STEMs have never been flown in space due to several technical risks. The Ω -shaped half-shell sheets are cured inside modularly constructed moulds
- To overcome future limitations of size, geometric complexity, and development costs, a modular out-of-autoclave heating device has been specified and designed. The device can be easily extended to nearly arbitrary length





The European Solar Sail Technology Status

PROGRESS IN DEPLOYABLE BOOMS (by DLR)

Out-of-autoclave heating device for very long affordable composite booms

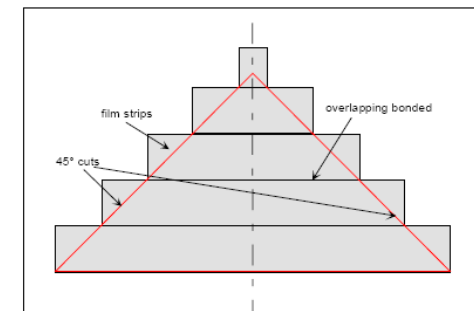


- Engineering test on reduced boom sections and full-scale tests on boom models from the pre-development phase demonstrated the performance of the boom concept. Both, thermal vacuum as well as mechanical tests proved the concept in the preliminary design phase and all preliminary specified mechanical boom performances were met by the development tests.

The European Solar Sail Technology Status

PROGRESS IN SAIL MANUFACTURING AND SAIL MEMBRANE STOWAGE (by DLR)

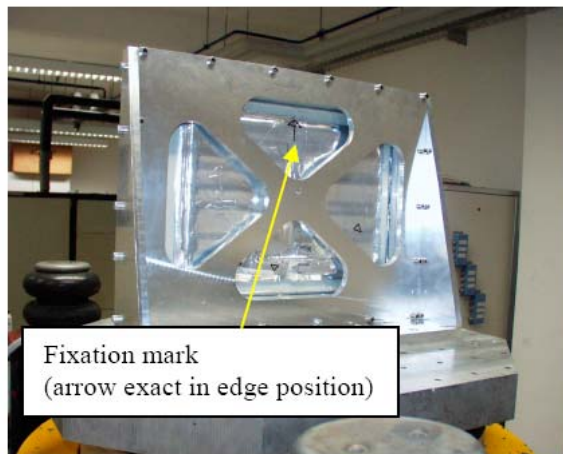
- **Sail membrane segments manufacturing:**
For the sail segments several upgrades and improvements in the manufacturing steps and processes were introduced by the DLR Institute for Space Systems. The manufacturing concept applies an overlapping bonding scheme of film stripes to form a triangle sail by 45° cuts at the ends of the joined sail films
- Supporting the specification of sail cutting and joining technologies a small-scale lab-model (a triangle of 9 m²) was manufactured. The goal was to get practical experience in manufacturing and handling of such ultra-thin film as well as to approve the pre-assembled material, the manufacturing tools and facility, the cutting and bonding processes as well as the membrane reinforcement methods.
- In support of manufacturing and handling a 6.6m x 2.8m vacuum-table was established. The use of this table assisted all steps of manufacturing greatly and reduce the risks to wrinkle the film.



The European Solar Sail Technology Status

PROGRESS IN SAIL MANUFACTURING AND SAIL MEMBRANE STOWAGE (by DLR)

- **Membrane fixation for launch – concept development and test :**
After detailed investigations on breadboard devices the complexity and conditional nature of the system with the components sail container, launch fixation, folded sail segment and sail restraint device is evident. Only a well coordinated system of these components can meet the requirements for the safe transportation of the folded sail segment into free space, the reliable and controlled unfolding and the successful deployment of the sail segments.
- The folded sail segment can be safe and careful stowed in the container only by a flexible surface fitted fixation. To ensure the fixation in the launch load phase a surface pressure of 10^{-1} N/mm² is recommended (at least $2 \cdot 10^{-2}$ N/mm² is required!). An isotropic pressure is absolutely essential, otherwise crack initiations and/or brake lines in folded ranges can occur. Therefore vacuum bag fixation is recommended.

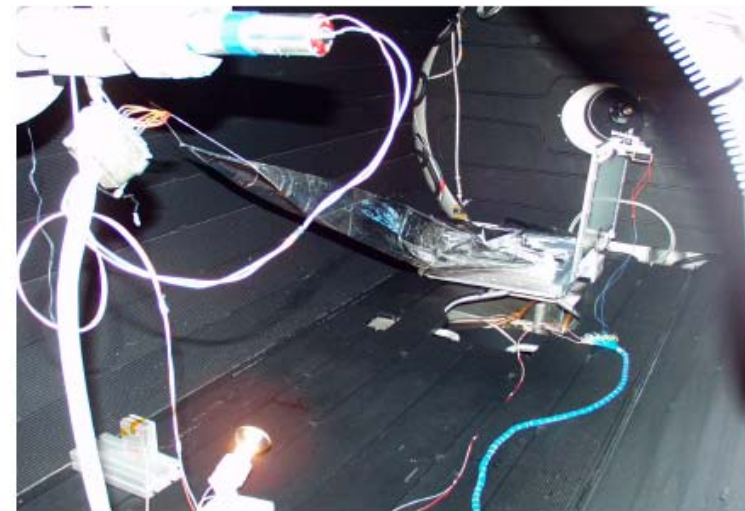
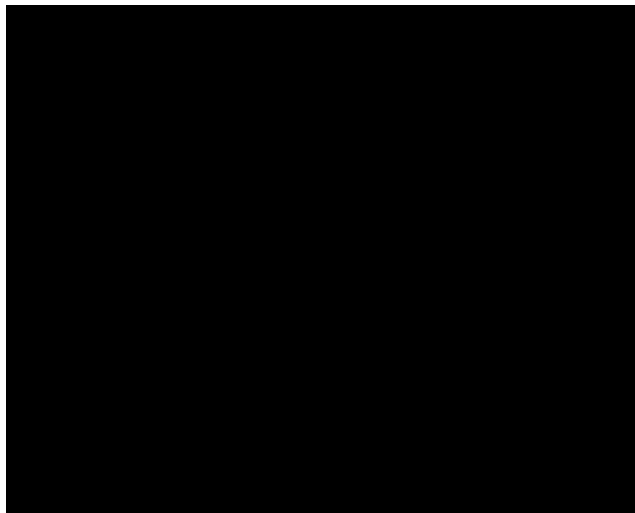




The European Solar Sail Technology Status

PROGRESS IN SAIL MANUFACTURING AND SAIL MEMBRANE STOWAGE (by DLR)

- The folded sail segment has to be careful evacuated (less than 10^{-2} Pa) before the container can be opened. Otherwise the residual gas between the folded sail foils will end in uncontrollable blow out of the sail segment before the deployment can start.
- When the recommended surface pressure level during launch phase is kept, the folded Kapton layers, VDA coated on both sides, survive all loading cycles in fixed position and there is no danger for sticking or welding effects. Pre-tests concerning this were realized by deployment simulation of a folded membrane under free space conditions in a DLR space simulation chamber in Berlin. The measured force for pull out the sail membrane after completion of all loading cycles never exceeded the specified maximum force.

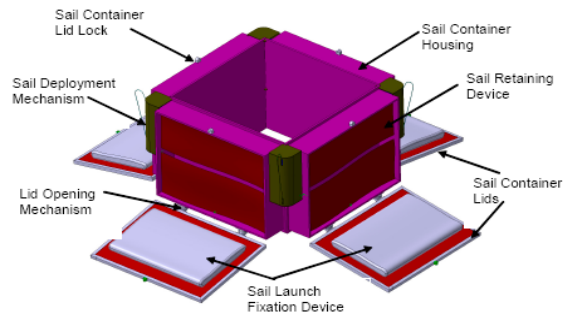




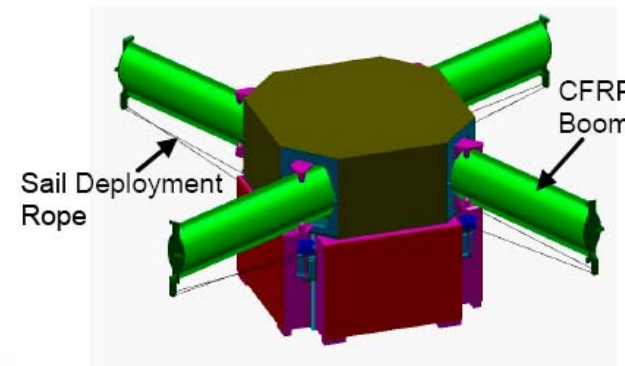
The European Solar Sail Technology Status

PROGRESS IN BOOM AND SAIL DEPLOYMENT MECHANISMS (by Kayser-Threde)

- For the sail containers a modular structural concept is developed, allowing easy replacement, disassembly, and simplifying the verification efforts for membrane deployment.



- The critical boom root mechanism which allows the boom root to fully deploy and latch in the deployed configuration was designed to meet the requirements of a compact and reliable compartment for stowing and deployment of the booms and sail membranes





The European Solar Sail Technology Status

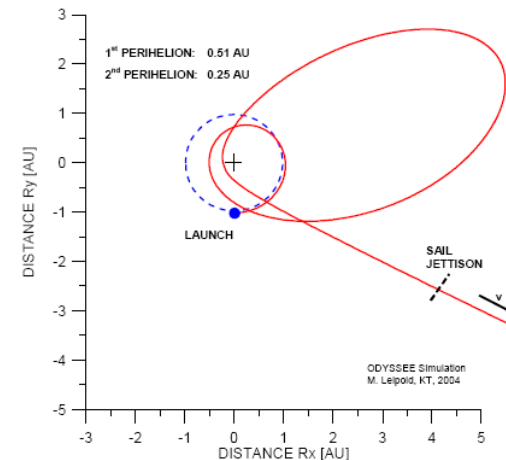
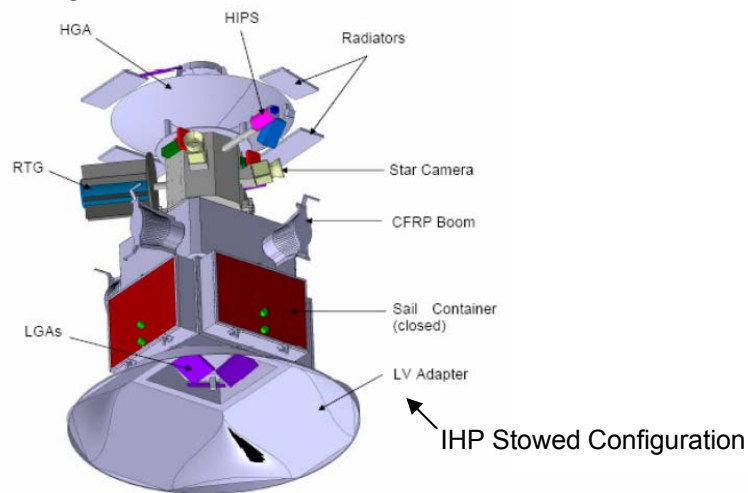
SOLAR SAIL MISSIONS FOR SPACE EXPLORATION

- Once developed, solar sails could open up the opportunity to realize challenging deep space missions with extreme Δv requirements which are beyond the capabilities of even advanced electric propulsion systems.

In planning stage are:

- A Solar Polar Orbiter (SPO), inclined 90° to ecliptic plane, to observe the solar poles
- Interstellar Heliopause Probe (IHP) aiming at 200 AU to study the local interstellar medium
- Comet Nucleus Rendezvous and Sample Return, using a separable lander vehicle
- GEOSAIL concept with a sail in an elliptical Earth orbit where the sail craft realizes a rotation of

the apse line to maximize stay time in the geosail region. SPO as well as the fast mission to the heliopause (IHP) is mentioned as candidate within ESA's Cosmic Vision outline for 2020-25.



IHP Transfer for $a = 1.0 \text{ mm/s}^2$ and Minimum Perihelion Distance of 0.25 AU (Ecliptic Projection)



The European Solar Sail Technology Status

SOLAR SAIL MISSIONS Conclusion

**Keep clean the Space -
use Solar Sail for
propulsion!**

I propose to do it step by step and to realize as first step the “In Orbit Deployment Demonstrator” to demonstrate the feasibility of reliable and sure deployment as well as stability and controlled flight of the full deployed sailor before next steps can follow!