

THE TERAHERTZ 20M SPACE TELESCOPE TALC, PROGRESS REPORT ON THE DEPLOYMENT OF THE 20M WHEEL STRUCTURE

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ABSTRACT

Further space exploration in the far-infrared (FIR) requires larger apertures in order to improve the spatial resolution of captured images. To this purpose, the Thinned Aperture Light Collector (TALC) concept of a deployable annular telescope has been developed at CEA and within the European consortium ELICSIR, which offers novel perspectives for FIR space missions. The general structure of TALC is one of a bicycle wheel. The deployment motion is thought as a reversible one, in order to let the telescope be packed again inside the fairing of the rocket to perform large numbers of automated cycles. The method for storage and the authority of the control is discussed here.

1. INTRODUCTION

In order to continue the exploration of the universe using far infrared spectrum, larger space telescopes are required. Lessons learnt from the James Webb Space Telescope is that this exploration will remain affordable only if a disruptive technology emerges, allowing to combine a very large aspect ratio from folded to deployed configuration, and a reliable deployment concept. To this purpose, the TALC project is currently under study by a European consortium.

The general structure is one of a bicycle wheel, where the inner side of the segments in compression to each other plays the role of the rim. The segments are linked to each other using a pantograph scissor system that lets the segments extend from a pile of mirrors to a parabolic ring keeping high stiffness at any time during the deployment.

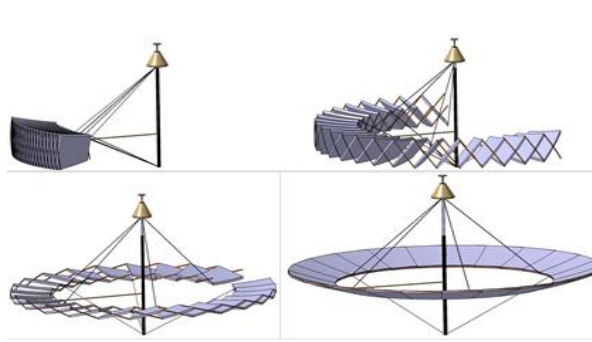


Fig. 1. The preliminary conceptual design of deployment of TALC in 2013 without parallel packing

The inner corners of the segments are linked to a central axis using spokes as in a bicycle wheel. The primary mirror has an external diameter of 20 m. Thanks to an original folding concept, it can be stored in the fairing of Ariane 6 during the flight, then deployed in space.

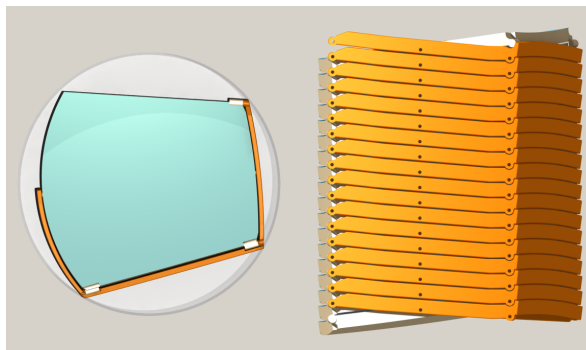


Fig. 2. The mirror segments stacked parallel in the fairing in 2014

Hence the thickness of the segments built of CFRP is about 0.2m, the aspect ratio of the 20m M1 parabolic mirror is the one of a membrane. The final shape of the mirror relies on active controls at various dimension scales. At scale below the size of the segment, the shape of an individual segment is controlled using piezo-electric unimorph control of tens to thousands of pixels. At mid-scale, actuators placed at the hinges of the segments let adjust the front wave difference from one segment to another. At large scale, the cable spokes are trimmed in length for both static and dynamic control. The actuators used to trim M1 mirror comprise both memory shape piezo-electric actuators and real time controlled piezo-electric actuators. These piezo-electric actuators may be used from room temperature down to 25K.

In this paper we present a kinematic model for a deployment breadboard from stacked parallel position in a fairing to a full deployment. Inside the fairing the segments are packed parallel to each other. This provides the best ratio of M1 surface to stacked volume for segments made of a CFRP sandwich honeycomb. This stacking also provides the best protection against vibration and contamination before and during the launch. During observation, the telescope is kept in the cylindrical shadow of a solar shield. The telescope has a hemispherical field of view at all times.

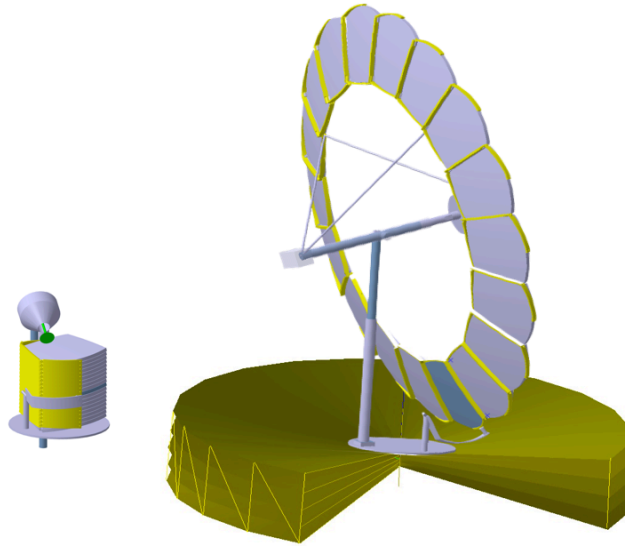


Fig. 3. View of TALC stacked in the fairing and after deployment behind a solar shield

2. TOPOLOGICAL CONCEPT

In TALC we abandon the concept of a rigid support structure for the segments of the primary mirror as used by JWST. The support structure consumes too much volume in the fairing and fundamentally is not required in the zero-g environment of space. The rigid support structure is replaced by an actively controlled “tensegrity” truss structure. Tensegrity structures were originally developed by Buckminster Fuller and Snelson and achieve structural integrity purely by tension, thus the name “tensegrity”. Since there are no bending moments, these structures can be extremely light and can be folded and stowed efficiently.

The masts and the inner edge of the segments are the parts in compression. They consist of the “altitude mast” that keeps the center of gravity of the telescope at distance from the solar shield and the “telescope axis mast” that is the main structure in compression at all times. The altitude mast takes efforts during the deployment whereas deformation is permitted. It also takes very small efforts during repointing. It is fully at rest during observation. The telescope axis mast takes efforts during the deployment. After deployment it is kept in axial compression, without any bending momentum. It takes very small bending load during repointing. A “mirror stack support” is used during launch and during the early phase of the deployment to position the stack of mirrors in front of the telescope axis mast. It consists of a short pylon and an arm “segment stack support” that surrounds the stack of mirrors. An actuator on an oblique axis at the top of the pylon is used to position the stack of mirrors from the launch position to the unstacking position in a single rotation.

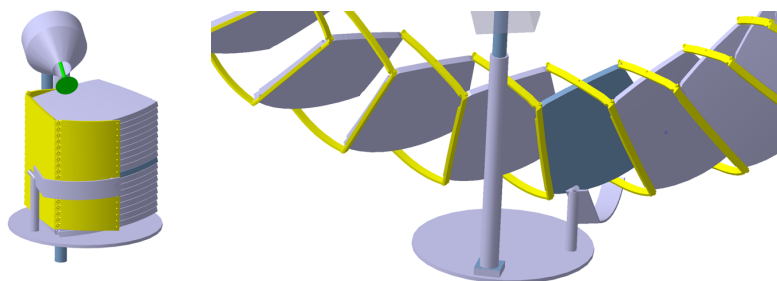


Fig. 4. Close view of the pylon and the segment stack support

The masts and the actuators (length, rotation) are used both for the deployment process and for the pointing of the telescope.

3. STORAGE AND EXTENSION OF THE SPOKES

The spokes consist of cables which are wound on a winch, the axis of the winch being actuated using a spiral spring, that produces a constant torque. This self-retracting system follows the extension of the spokes during the deployment process of the parabolic mirror. The spokes are either aligned at small force by the winch system or stretched at working length. A hardware limit blocks winch when the spoke is fully extended. There is no existing design for this setup at this time. The spokes are connected to the ends of the telescope axis mast and to the inner corner of the segments at all times. The design constraint was to keep free the area between the mirror stack and the axis mast at all times during the deployment, in order to keep out the spokes from friction and risk of embracing. Pockets in the segments will be reserved to install the winch mechanism of the spokes. During the deployment of the stack, the lengths of the spokes are unequal until the mirror is deployed as a full ring. For this reason, the set of actuators will be controlled in a synchronous way, so as to keep at least 4 spokes at full length at all time, while the other spokes will remain aligned by the winch system. By keeping at least 4 spokes at maximum length under tension, the partly deployed telescope is controlled at full time at a wanted position, without play and with a way to damp possible oscillations.

4. AUTHORITY TO CONTROL OF THE DEPLOYMENT

The first part of the deployment consists of the raising of the masts and the tilt of the stack of mirrors using the mirror stack support. At this stage, both the masts and the the stack of mirrors are kept in position as rigid cantilever systems. These mast and supports shall be stiff enough to pull the spokes out of their winch without generating excessive deformation or oscillations. The altitude mast and the telescope axis are positionned in front of the stack of mirrors. The length of the telescope axis is adjusted until at least 4 spokes reach their full length to stop the play. In this situation the system becomes isostatic, the position of the stack of mirror becomes defined by the length of the spokes, the masts and the position of the ball joint situated at the link to the mirror stack support. At this stage of the deployment, there is no need any more to set the orientation of the mirror stack using mirror stack support, the rigid junction between the segment stack support and the segment stack may be released to a ball joint.

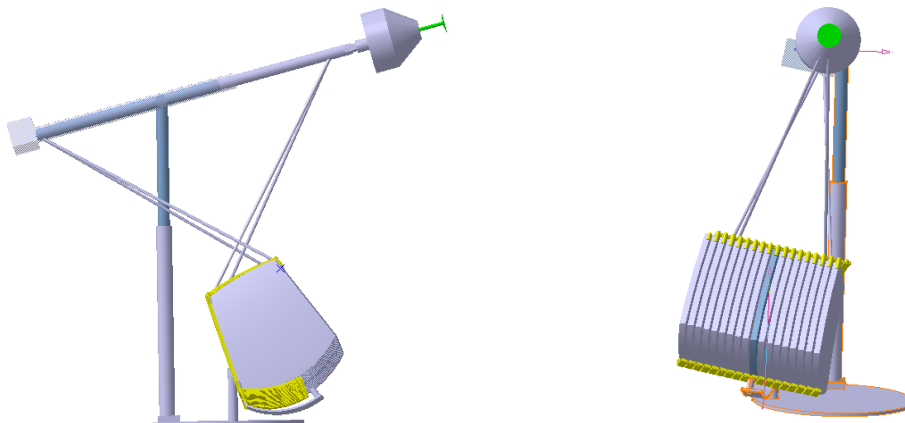


Fig.5. Position before expansion of the stack of mirrors

As seen in the pictures, the telescope is maintained by at least 3 points at all times of the deployment, with a strong authority on the position. This is made possible by the analysis of the stiffness of the various components of the system.

The circumference of the set of segments is controlled by the “circumference actuators” which sets the angle between segments and arms of the pantograph system.

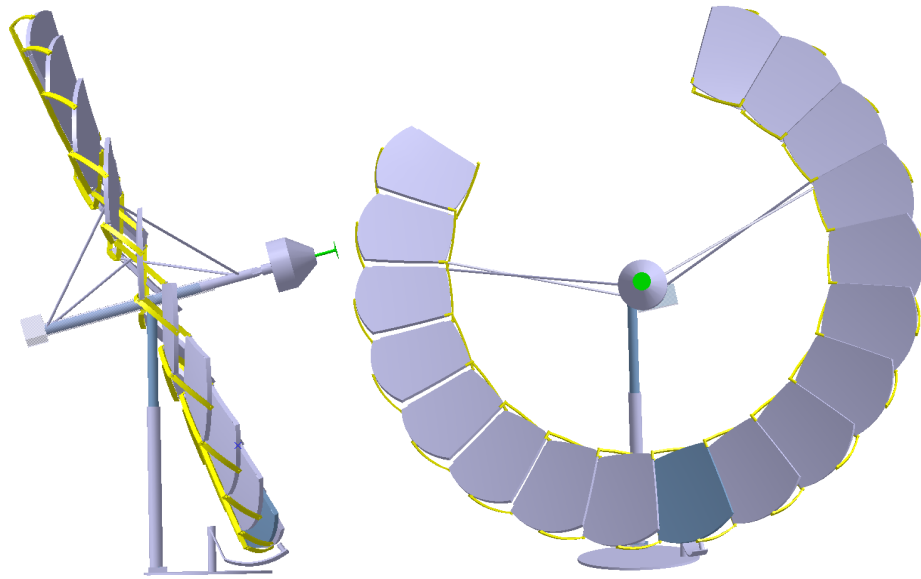


Fig. 6. Extension is $\frac{3}{4}$ of the circumference, telescope axis has its smallest length, since the trajectory is wider than the final diameter of the telescope.

The second phase of the deployment starts, the circumference actuators extend the set of segments, while the telescope axis actuator is adjusted to keep 4 spokes stretched at full length. It has been surprising to understand that the length of the axis decreases until the extension reaches $\frac{3}{4}$ of the final circumference. For this reason, the prime authority on the control relies on the circumference actuators, and not on the length of the telescope axis that cannot power the system since it goes to a minimum value at $\frac{3}{4}$ of the extending process.

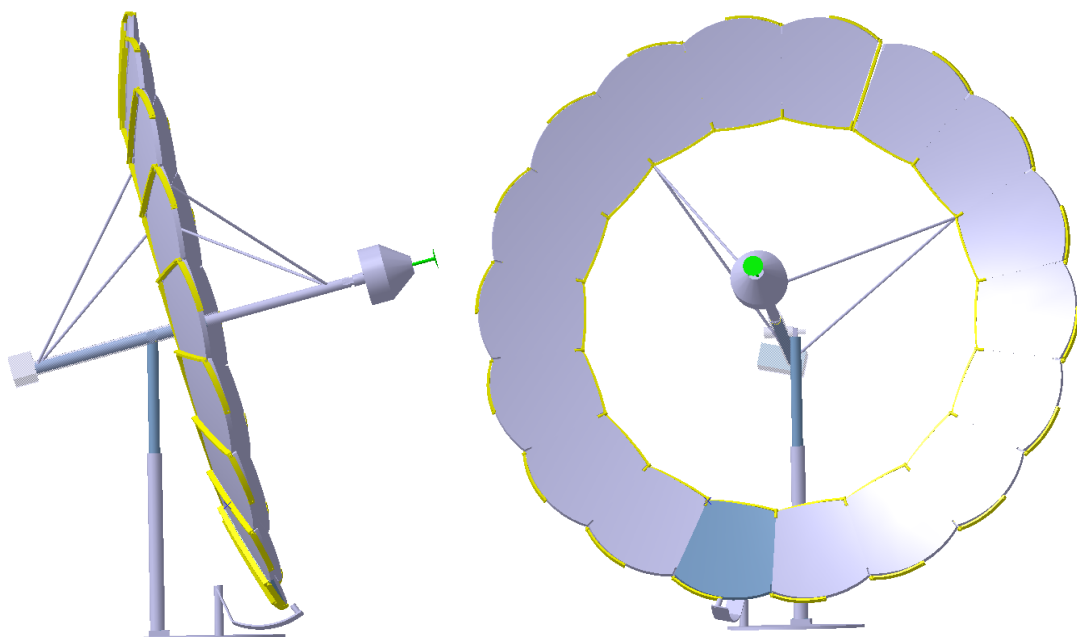


Fig. 7. The telescope is fully deployed, the telescope axis is at its maximum length. All spokes have equal length.

The length of the arc of the partly deployed stack of mirrors is controlled by rotation actuators placed between the segments and the arms that constitute the pantograph. Actuators are built every few pair of segment-braces, in order to keep a stiffness along the circumference.

5. OPTIMAL USE OF THE SPACE IN THE FAIRING

The segments fill the useful area of the diameter of the fairing at maximum area. Most wanted areas are the corners of the segments and the outer diameter of the petals. Therefore, the segments follow the shape of the fairing at their outer edge, in order to maximize the diameter and the resolution of the telescope. The space of the segment towards the central hole of the telescope is less critical since this hole mainly reduces the photon flux but plays a smaller role in the resolution. For this reason, the masts are stored towards the inner side of the segments. The space on the side of the segments is also used for the pylon and mechanism of the mirror stack support. The M2 mirror and the instrument case are situated at the top of the fairing.

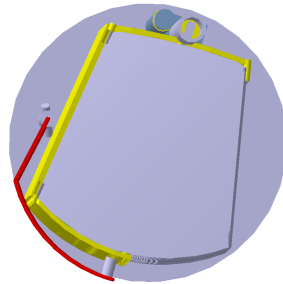


Fig. 8. Top view of the mirrors and masts inside the fairing

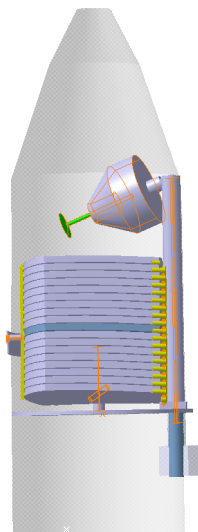


Fig. 9. Talc packed inside the fairing of Ariane 6

6. POINTING AREA

The proposed topology is compatible with a hemispheric area. The telescope is in rotation inside a spherical space allocation, protected by the cylindrical solar shield. Therefore, it is possible to point any direction from transverse to the back to the sun.

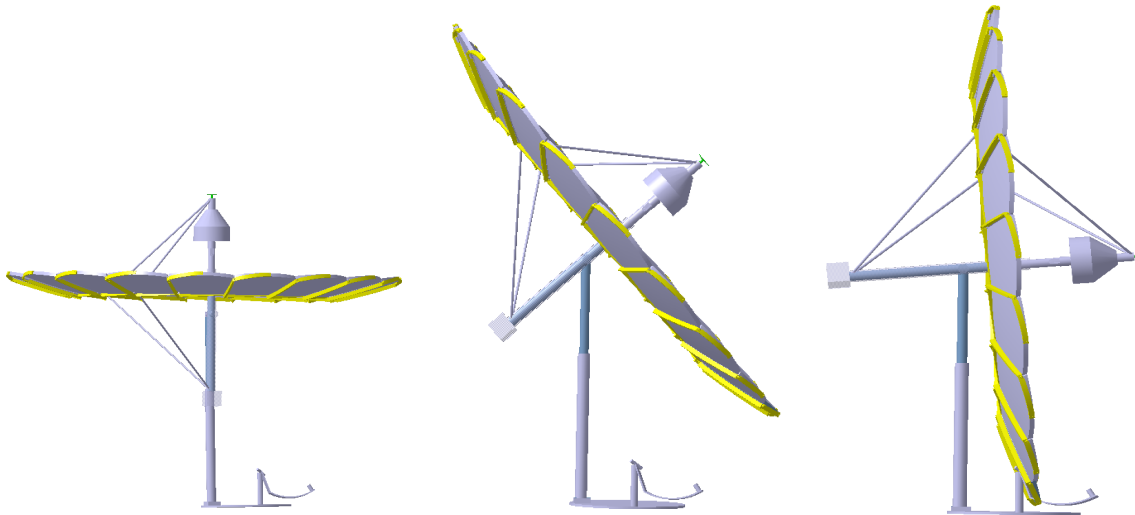


Fig. 8. Pointing area from zenith to horizon

7. DESIGN DIAMETER OF THE TELESCOPE AND FUTURE WORK

The diameter of the telescope is not directly linked to the diameter of the fairing as in the case of JWST. The ratio is a function of the number of segments. Using thin segments at the diameter of the fairing, whose reflecting surface is electrically controlled by unimorph piezo control placed at the rear of the segments, the number of segments may be increased to more than 18 segments as represented in this article. The space industry is making a lot of progresses in the design of CFRP mirrors. This is the case with recent developments of thin ply technology honeycomb and flanges. Other developments are made on the unimorph piezo control, using online control or memory shape piezo cells. One area is still lacking development is the ability to build mirrors by replica in dimension of 4 meters, with visible optical quality, that are stable at low temperature and with small moisture coefficient. Several ideas shall be envisaged: nanotube cyanate ester, thin nickel coating, Kapton laminate as front layer. However, these developments are useful for a wide community, and do not require extreme high effort of our group as a unique feature for TALC. The manufacture of a breadboard at dimension of 1 meter, without gravity compensation and at a diameter of 4 meters including gravity compensation is the rupture technology that is required to increase the TRL level of the TALC telescope.

We will first manufacture a 18 segment breadboard with a ration from fairing useful diameter to telescope of 4 that would correspond to a 20m telescope. With increasing experience, 24 and later 36 segments might be proposed in order to build telescope of diameters 8 times the fairing for a space telescope up to 40 meters. This is accessible with active mirrors 10 to 15cm thick and telescopic masts built with 4 segments.

CONCLUSION

While the manufacture of CFRP sandwich ultralight mirrors using surface shape control is required for the TALC telescope, it is part of other space research programs. The deployment of the wheel structure and the spokes of TALC is a unique feature which is the key for deployment of a very large space telescope that gives access to ultra-high resolution and collecting surface. The construction and the test of corresponding breadboards is needed to reach a reasonable TRL on this concept.

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