Flat-Fabrication of Progressively Self-Assembling Space Systems

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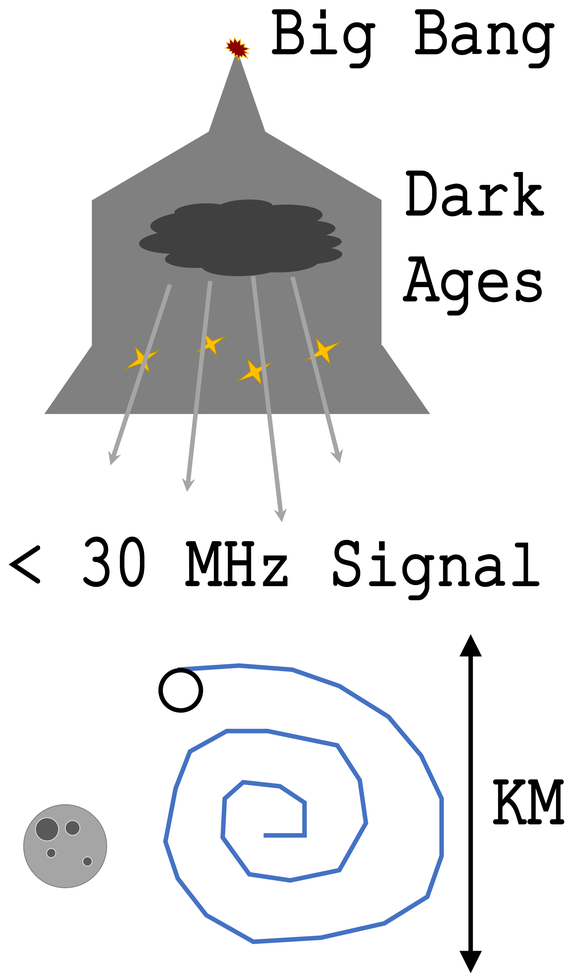
NASA Innovative Advanced Concepts

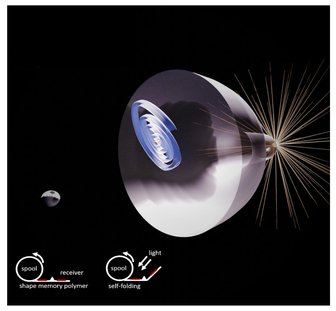


The challenge

- The universe remains largely uncharted within a narrow band of frequencies nearby and below 30 MHz
- Earth's ionosphere and anthropogenic radio emissions almost completely impede radio astronomy from the ground for frequencies below 30 MHz
- Kilometer-sized antenna arrays are required to observe such a frequency range with high resolution
- Because of the required size, space-based antenna arrays are hard to realize

Our solution concept

We seek to utilize a self-folding SMP bus with embedded sensor units to develop a large scale, space-borne antenna array capable of capturing signals in the frequency band nearby 30 MHz



1. Embed sensors on an SMP strip. Wrap the strip on a spool, without permanently deforming the strip
2. In space, the strip of sensors may be slowly deployed by rotation of the spool or by ejection in a single shot
3. When exposed to solar energy, self-folding of ink hinges printed on the SMP bus induces a predetermined deformation of the strip of sensors that, consequently, evolves into a large spiral

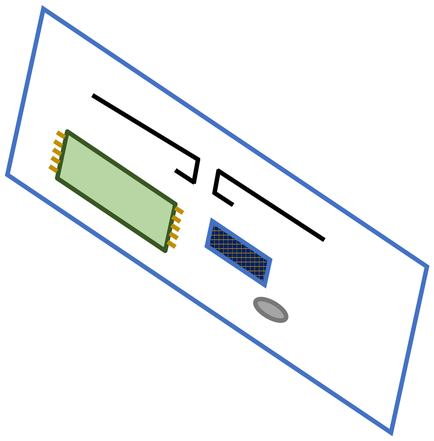
Innovation

Our proposed antenna array for space-based radio astronomy differs from existing concepts in that it does not rely on lunar surface infrastructures, monolithic architectures nor free-floating swarm solutions. The structure self-assembles in space when exposed to solar radiation.

Mass and size

An antenna array with a 3000 m baseline can achieve a resolution of about 44 arcsec on the redshifted 21-cm radiation.

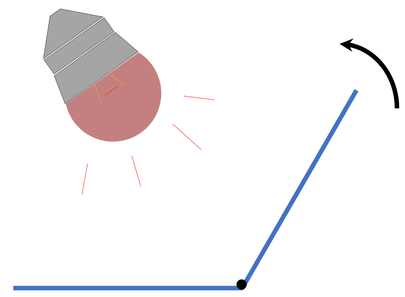
- A 3-turns spiral with a maximum diameter of 3000 m is about 14.9 km long
- Assuming a thickness of 0.3 mm, a 14.9 km long spiral can be wrapped on a spool with an internal diameter of 0.5 m and an external diameter of 1.5 m
- A SMP strip made of polystyrene that is 14.9 km long, 0.3 mm thick and 10 mm wide weighs about 45 kg (assuming a density of 1050 kg/m^3)



What are shape memory polymers (SMPs)?

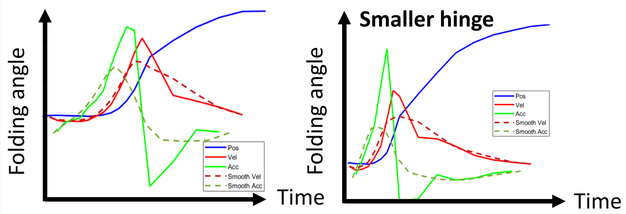
We use SMP sheets that shrink to half their original size when heated. We pattern the sheets with opaque ink and expose the samples to infrared (IR) light. The polymer is transparent to IR light, but the ink absorbs the IR light and heats locally. This creates a gradient in temperature and shrinking through the thickness of the sheet, which causes the sheet to fold. Upon removal of the IR light, the sample cools and the folded shape is maintained. Ink patterns can be combined to create complex, self- folding structures.

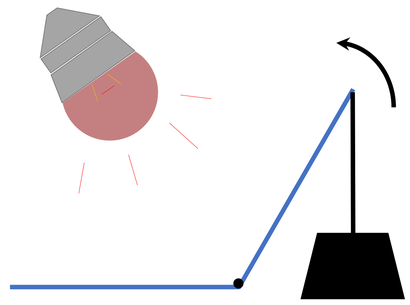
IR light



Torque experiments

We can estimate folding torque by an inertial analysis of folding angle measurements.



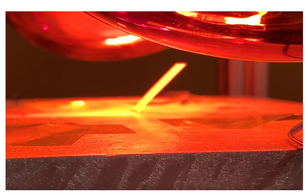


Opaque sky below 30 MHz

Energy flux and transition temperature

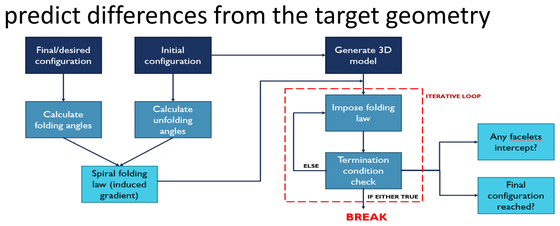
- In lab conditions, ink hinges are activated at reported energy flux values around 1 W/cm^2. Solar radiation flux at 1 AU is around 0.13 W/cm^2. We are conducting experiments to study folding behavior at reduced radiative power input
- Typical SMP glass transition temperatures are in the range of 36-96 ^{o}C, depending on the polymer used; higher transition temperatures are also possible

In space, the equilibrium temperature of the deployed system should be kept below the SMP transition temperature to avoid unintentional folding.

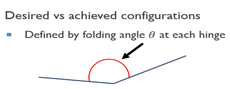


Simulating unfolding

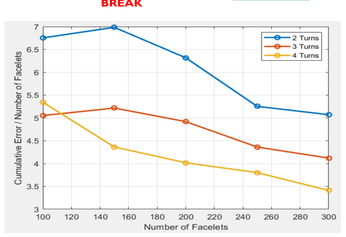
We utilize kinematic principles to numerically simulate unfolding of the spiral antenna array and predict differences from the target geometry



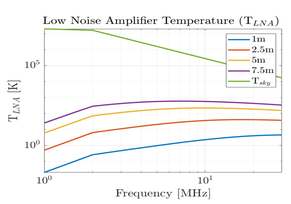
- Desired vs achieved configurations
  - Defined by folding angle θ at each hinge



- Net error
  - $e_{hinge} = \theta_{wanted} - \theta_{got}$
  - $e_{total} = \frac{sum(e_{hinge})}{\#\ facelets}$
- Cumulative error
  - $e_{hinge} = |\theta_{wanted} - \theta_{got}|$
  - $e_{total} = \frac{sum(e_{hinge})}{\#\ facelets}$



Antenna array



Active dipoles for the reception of the Dark Ages signal may enable a shorter antenna length. To be effective, the system must be sky-noise temperature limited.

Independent wireless sensors mitigate the effect of single point failures. Preliminary analysis shows that low power is required for the wireless transmission of data from the array elements to the central hub.