Chris Johnson / Ross Greenwood

The Physics Our best models of the early universe incorporate a period of incredibly rapid expansion known as cosmic inflation, during which the universe doubled in size at least 100 times over a tiny fraction of a second. This follows from Einstein's general theory of relativity, which explains the effects of gravity in terms of the geometry of a unified space and time. During inflation, an exotic kind of stuff with negative pressure (tension) induced a nearly constant curvature in space-time, causing the wild expansion. Cosmologists studying these space-times represent them by drawing negative-curvature surfaces (like a saddle) in our familiar three dimensions of space, to serve as a visual and mathematical aid. With the right interpretation of how distances are measured, these surfaces have the same geometry as space-time during the very early universe.

The Piece The piece is a solid cylinder of clear glass with a negative-curvature shape embedded inside. This inner hyperboloid is made of glass with a higher Coefficient of Thermal Expansion (CTE) than its surroundings. As the piece cooled, the inner glass contracted more than the outer glass, resulting in a perpetual tension frozen in at the boundary surface. Around the sites of tension, the glass deformed at a microscopic level, producing a higher degree of order in the molecular arrangement, and establishing a preferred direction or "grain". By shining polarized light through the piece and observing through a polarizing film, we can see a visual manifestation of perpetual tension bringing about the geometry of space-time in the early universe, as it did during inflation.

Our Challenge How to create tension in glass in the opposite way that glass typically gets stressed? Normally glass is stressed from the outside due to uneven cooling; the outer surface cools more rapidly than the inside. To prevent stress, cooling is controlled by placing the object in a kiln so that the inside falls in temperature at the same rate as the outside, allowing the glass to harden or "anneal" properly. If the temperature drop is not gradual, the glass on the outside will cool and start to shrink while the glass in the interior –insulated by the outer layers – will remain hot, and will not shrink. The difference creates stress on the outer glass, which will eventually fracture due to the unbearable pressure.

In order to represent cosmic inflation for this exhibit, we created a stressed form in the core of the piece. To do this we had to invent several new techniques, which required research and experimentation using the scientific process. Our aim was not only to create stress on the inside of the piece but to represent the particular form of a hyperboloid. To our knowledge, this idea has never been used to create art before. This is new and exciting territory for both of us.

Our Process Tension can be induced in two ways. The first is through heat stress, where the core of the piece is allowed to cool down below its strain point and then quickly encased in a new layer of hot glass. The final form is then placed in the kiln to cool before the core has had time to come into thermal equilibrium with the outer layer. Thus, tension is trapped inside the outer casing. In the second method, two different chemical formulations of glass are used, resulting in differing coefficients of thermal expansion; one formulation will shrink more than the other, irrespective of the rate of cooling. The trick here is that if the CTEs are too dissimilar, the glass will separate and crack. In our research we were unable to find published or even anecdotal information about the limits of this interaction, and so had no idea of how far we could push the difference. The only way to find out was through a series of experimental trials.

Artist's Statement Finally I have my own captive physicist! I have been attending and listening to science lectures for as long as I can remember. What has always frustrated me is that during Q&A somebody will ask an interesting question about some aspect of physics, which then suggests a continuing line of inquiry. But the next question that comes along is usually completely unrelated, and so there's no in-depth exploration of the topic. In this collaboration with Ross, I have been able to ask the questions and the follow-up questions. Ross has been very generous in attempting to answer all my questions. I may not understand all the answers, but at least I get to ask the questions!

In art, my main focus has always been color. When making a piece I typically use multiple layers of color to achieve rich saturation. For this collaboration, instead of adding color to the piece, we are inducing the glass to produce color through the internal stress. This project has challenged me with new questions of how to realize a vision in glass. Ross wanted to work in Stress or Tension because that is his mental model of the work he is doing. I had never considered working in glass this way.The project has forced me to innovate in ways that I never would have come up with if this question of how to express a vision of cosmic tension had not been presented.