fq(x) News

A Perfect Match

Andrei Linde and Renata Kallosh believe that string theory and cosmology are a marriage made in the heavens.

by **WILLIAM OREM**

FQXi Collaboration: Andrei Linde & Renata Kallosh July 18, 2008

When you work in one of the most complicated fields in modern science, it's good to be concise. "We met when we were both in Russia in the same institute," Andrei Linde says of his wife and fellow researcher, Renata Kallosh. "After a while we married, and for more than thirty years we live together and sometimes collaborate."

ANDREI LINDE
Stanford University

That's the story in a nutshell. In the details, however, things become more complex.

Both Linde and Kallosh are professors of physics at Stanford University, California. She works on such heady topics as supergravity and superstrings. He, meanwhile, is one of the fathers of inflationary theory, and among the biggest names in modern cosmology.

There was a time when the worlds of string theory and cosmology were as separate as events outside each other's light-cones (or night and day, depending on your background). Recently, though, these disparate research areas have started to come together. Like masses in an unstable orbit, their approach has been tentative, then rapid, and finally explosive.

Chaotic Beginnings

A prolific author and thinker, whose work has been discussed in *Time*, *Wired* and *The New Yorker*, Andrei Linde's name is most strongly associated with one grand idea: eternal chaotic inflation, or ECI.

The roots of ECI came about after considering a mystery raised by the big bang model and the fact, discovered by Einstein, that nothing can travel faster than the speed of light.

> For more than thirty years we live together and sometimes collaborate.
> - *Andrei Linde*

The mystery was that the universe, overall, looks pretty much the same in every direction—but nobody could explain how this came to be. To understand why the homogeneous nature of the universe was such a conundrum, imagine a room full of people all singing "happy birthday." At first, everyone starts on a different key, and at slightly different times. Before the verse ends, though, all the voices come together. Such homogeneity can only emerge if everyone in the room has had enough time to listen to his or her neighbors and adjust accordingly.

Similarly, a simple 180° pivot of the telescope brings into view galaxies on opposite sides of our homogeneous universe, and by the same argument used for the singers at the birthday party, these regions must have communicated information about their state.

However, the speed of any such communication is limited by the finite speed of light. The puzzle that cosmologists faced was that the universe has not existed long enough for the required information to have been communicated between such far away regions in this way. How, then, could the overall picture be homogeneous?

A brilliant solution to this puzzle was proposed in 1980 by Alan Guth, now the Weisskopf professor of physics at M.I.T., and expanded on by Linde and others: inflation.

RENATA KALLOSH
Stanford University

According to inflationary theory, the region of space-time that we call the universe originated from a small patch in which all the parts were in close enough contact to share information. Early in the universe's history, a burst of faster-than-light expansion, or inflation, occurred in this patch, rapidly hurling neighboring parts to far flung reaches. This was the equivalent of instantly transporting each "happy birthday" singer thousands of miles away while they were still finishing their last note, creating homogeneity over a vast expanse.

Over the years, the inflationary model has itself been expanding. Under the attention of Linde and others, it has continued to undergo mind-bending modifications. The latest view from the mountaintop is staggering, both in its weirdness and its beauty.

Bubbling Multiverse

If the discovery of inflation was the opening theme, eternal chaotic inflation is the first movement of the symphony. In ECI, the big bang was not *the* beginning. Rather, it was *a* beginning—only one of many. "We no longer can say there was *one single moment* for the whole universe when this happened," says Linde. "It could be that different places were created at different times."

ECI views our universe, then, not as a unique phenomenon, but as one particular universe among many, each of which has its own laws of physics. The image commonly invoked here is foam on a head of beer: a roiling mass of inflation in all directions. Such a picture is sometimes called the "multiverse" to designate an unending series of bubble universes, each one undergoing its own cycle of birth, expansion, and potential collapse. The bang has become the bangs.

OUR UNIVERSE
or the one next door?
(Credit: *NASA*)

The process has no limit; each universe creates the space-time it occupies as it goes along. And it has no end in time—inflation is eternal. So how can cosmologists tie down the physics underlying this sprawling, chaotic multiverse?

Answer: with string. And in particular, by collaboration with string theorists.

Superpartners

"I started learning cosmology from Andrei Linde, so I was really lucky that he was around," says Renata Kallosh. "I know better issues in this formal, mathematical field of string theory, but to bring string theory to the real world you have to know cosmology. For me, this collaboration was invaluable."

Kallosh, like Linde, earned her doctorate at the Lebedev Physical Institute in Moscow, in what was then the Soviet Union, before becoming a scientific associate at CERN, in Geneva, Switzerland, and now a professor at Stanford.

Through most of this time, the focus of her attention has been on the rarified world of superstrings—those subatomic somethings whose vibrations are hypothesized to give rise to particles and forces. If some version of string theory is correct, we may finally be able marry general relativity with quantum mechanics—the holy grail of physics, since Einstein's day.

> To bring string theory to the real world you have to know cosmology.
> — *Renata Kallosh*

"Fundamental physics has a huge problem: we don't know how to build quantum gravity," she says. "String theory is the best-known approach to this problem."

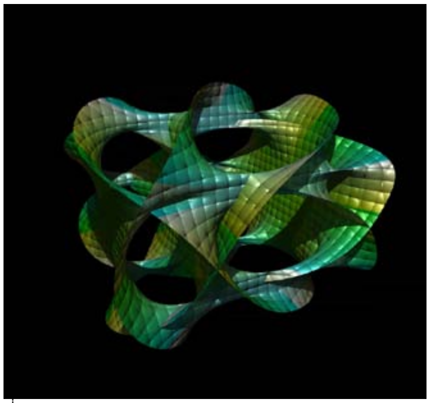
String theory, like cosmic inflation, has gone through many permutations since it was first introduced in the 1970s. But a funny thing happened on the way to unification: the theory started suggesting a connection to cosmology. Before long, it became necessary to take strings off the blackboard and into the broader world of astronomical research.

Crossing Fields

This is where the collaboration of Linde and Kallosh bears fruit. In a way, their relationship mirrors the overall progress of theoretical physics in our age: inflationary cosmology coming together with strings, the study of the inconceivably vast with that of the unimaginably tiny.

Shamit Kachru, at Stanford University, has done seminal work on the topic of "string compactification," stabilizing the extra dimensions that string theory posits in a way that naturally yields cosmic expansion. He has collaborated with Linde and Kallosh in the past.

"I was already tenured when I worked with Andrei and Renata, but I think it's fair to say that two papers we wrote together are two of my favorite papers," he says. "They [helped] to launch not only our own but also other people's investigations of the links between string theory and cosmology."



COMPACTIFICATION
Wrapping up extra stringy dimensions could tie up cosmic loose ends
(Credit: *Paul Bourke*)

Kachru views such field-crossing efforts as a powerful force in modern research. "The number of important results that come out of collaboration between people of slightly different backgrounds is tremendous," he says. "They really do involve interplay of people who are educated in different ways."

These days, in fact, collaboration between string people and cosmology people is all the rage.

"To give you a funny example, I had an invitation to give a talk at the *Strings 2008* conference at CERN," Kallosh says. "The way the invitation was written was, 'Of course you are welcome to speak about any topic . . . but we would be very happy if you would give us a mini-review on string cosmology!'"

Suddenly, everyone is interested in their kind of union.

"I'm also working on other very formal, very stringy topics, which were always part of my skills," Kallosh says. "But, at this moment, people want to know about string cosmology. I'm happily working on it . . . with Andrei's help."

Separate Streams

Given the vast complexity of modern science, such collaborations may necessarily be the way of the future.

"Collaboration has grown more important because we know a lot more than we used to and it's just harder to stay on top of everything," Kachru says. "If you have different expertises, the chance of making a real breakthrough is larger."

> I am trying to learn from her, she is trying to learn from me.
> - *Andrei Linde*

Being a married couple working in high-level physics has its benefits as well. Insight in either partner can be nurtured by discussion, while individual creativity can maintain its own space. Linde compares his and Kallosh's scientific thinking to the natural flow of water. "Sometimes it goes in parallel, but most often it goes like two separate streams that sometimes intersect," he says.

This vision of intersecting streams is mirrored in the increasingly synthetic approach to physics being taken by research as a whole. While many perceive scientists to be "lone geniuses," the next wave of discovery will more than likely be collaborative.

Unification

"There are physicists who have tried to work in a vacuum," laughs Guth, who is co-authoring a paper with Linde and a group of other cosmologists. "Probably the only people who have succeeded in doing that were Newton and Einstein. For the rest of us, collaboration is crucially important."

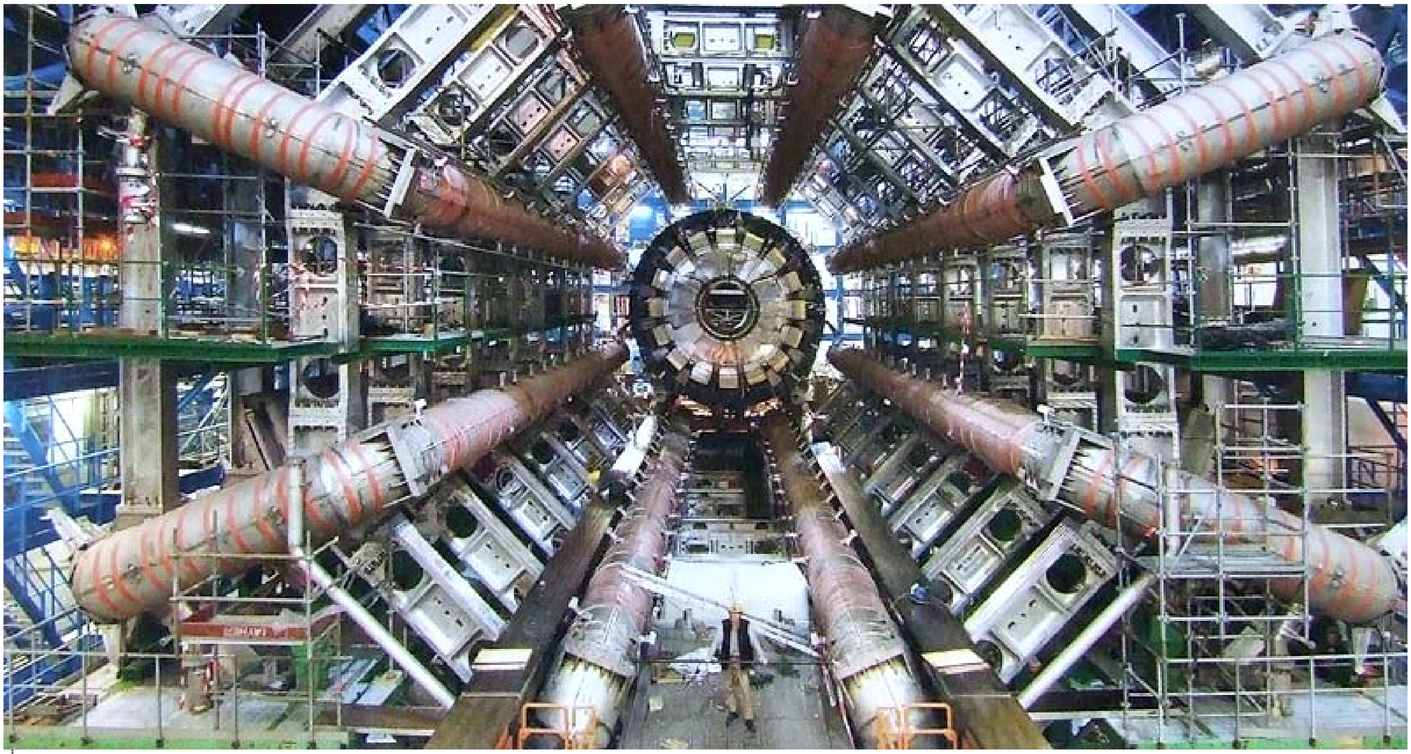
Guth adds that typical experimental collaborations in astrophysics and particle physics can involve hundreds or thousands of people. "On the theoretical side collaborations have also gotten larger," he says.

Kallosh cites the Large Hadron Collider (LHC), the particle accelerator at CERN, as an example. "Soon the LHC will start giving new information on particle physics," she says. "But we know it will be difficult to interpret this data unless you also can digest all the data from the sky—all the observations from astrophysics and cosmology."

She believes that the new generation of physicists will learn to be experts in particle physics *and* astrophysics *and* cosmology: "The distinction among which existed in the previous generation is likely to disappear."

Such a vision of the future brings to mind the meeting of inflating bubbles in the multiverse, and, indeed, Linde and Kallosh's personal intersection. And perhaps the metaphor is not too far off the mark.

"I'm trying to learn from her, she is trying to learn from me," Linde says. "We are trying to expand into each other's area."



CRADLE OF COLLABORATION
Will the LHC provide evidence for string theory?
(Credit: *CERN*)