Predicting The End

How does the universe end? One collaboration works to find out. The answer may be in the stars.

fq(x) News

by GOVERT SCHILLING

FQXi Collaboration: Fred Adams & Greg Laughlin — June 13, 2008

The future's uncertain
and the end is always near.

Jim Morrison, in the 1970 Doors' song "Roadhouse Blues," expressed the uneasy feeling many people experience when pondering things to come: We're afraid to get old and sick; we're anxious to see how our stocks will fare; and we worry about global warming.

FRED ADAMS
University of Michigan

But physicists Fred Adams and Greg Laughlin don't subscribe to Morrison's view. Their outlook on the future is more sanguine than anxious – and the end is very, very far away. True, Adams and Laughlin aren't trying to predict the stock market or Earth's climate; instead, they focus on the long-term future of the universe – the very long term, that is, in which mankind's musings and miseries are gone in the blink of an eye, and the reliable laws of physics permit a relatively solid forecast.

Ever since it became clear that stars have finite lifetimes and that the universe is an ever-changing place, people have been thinking and arguing over the long-term future of the universe. What will happen when the sun swells up into a red giant star, a few billion years from now? Will the universe become a dark and barren place when the formation of new stars shuts down forever? What's in store for the universe as a whole: Will it expand forever, or start to contract toward an apocalyptic big crunch?

In 1969, cosmologist Sir Martin Rees of Cambridge University was the first to seriously consider questions like these. "It was all rather amusing," recalls Rees. "In principle, it's pretty straightforward to calculate what will happen under certain assumptions, but it was like an intellectual game. Quite a lot of fun."

> We should write a book.
> *- Greg Laughlin to Fred Adams, after news of their work hit the front page of the New York Times*

By the mid-1990's, enough work had been completed by Rees and others that when the University of Michigan in Ann Arbor held a college-wide theme semester on "Death, Extinction and the Future of Humanity," Adams – a professor of physics there – felt he could put together a pretty good class on the "death of the universe." The project sounded fun to Laughlin – then a postdoctoral fellow working with Adams – who dived in with related work.

And, just like that, Adams' and Laughlin's own long-term future was set: a class, a paper, a book, a friendship. "It's been a wonderful experience," says Adams. "We had a seamless collaboration."

Past

Adams and Laughlin first met in the early 1990s, at a Berkeley meeting of the American Astronomical Society and at a conference in Heidelberg, Germany. They got along pretty well, so when Adams needed to fill in a postdoc position in 1995, he invited Laughlin to apply. "I arrived in Michigan in October," says Laughlin, who did his PhD research at the University of California in Santa Cruz. "Around that time, the discovery of the first extrasolar planet was announced." Originally, Laughlin worked on problems related to star formation,

GREG LAUGHLIN
UC Santa Cruz

but he soon became interested in planet formation, too.

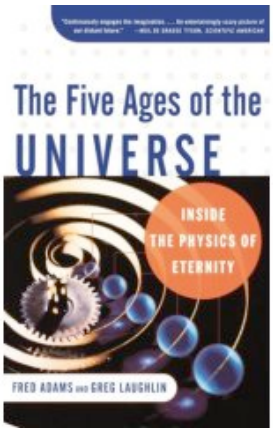
In fact, says Adams, most professional astronomers are more acquainted with their work on planets than with their collaboration on the distant future of the universe. "In some sense, this was more like a hobby project," adds Laughlin. Occupying adjacent offices, the two scientists discussed their ideas on the long-term history of the universe over coffee, or while driving around in the neighborhood. "We both had this same interest. It wasn't a planned thing," says Laughlin.

Their class was an immediate hit, so the pair decided to write up their new ideas in a rather technical review paper, which was accepted for publication in

Review of Modern Physics in January 1997. "That same month, at the winter meeting of the American Astronomical Society in Toronto, we also presented our results at a press conference," says Adams. "It hit the front page of *The New York Times*, and it was featured on CNN.

That's when Greg said: "We should write a book." But to fill a book, the two needed more material. So they looked to the stars.

In graduate school, Laughlin had studied the evolution of brown dwarf stars – "failed" stars that have too little mass to fuse hydrogen into helium. It turned out that their internal structure would



FRUITS OF COLLABORATION

slowly evolve for "hundreds of quadrillions of years," says Laughlin. Together with Adams, he then studied what would happen if two brown dwarfs would someday collide and merge – an extremely low-probability event, which only becomes frequent if there's enough time available. They found that brown dwarf collisions would produce a new population of low-mass stars, which would lighten up the universe once more, well after regular star formation has ceased altogether.

Next, says Adams, they tackled the question of the long-term fate of small stars. "They have less nuclear fuel than the sun," he says, "but they burn it at a much lower rate, so they live much longer than the sun does." Their calculations led to an interesting surprise: In terms of nuclear fusion, the sun has access to only ten percent of its mass, but, by comparison, a low-mass star can access much more of its mass, enabling it to live even longer than people had anticipated, up to ten trillion years. The calculations also showed that stars weighing less than 25 percent of the sun's mass wouldn't evolve into red giants. Instead, they stay small but become bluer over time. Says Laughlin: "Indirectly, we were able to better understand why sun-like stars become red giants at all – something which was not altogether clear."

With this material and more, their popular-level book *The Five Ages of the Universe*, published in 1999, was a huge success. "Writing the book was fun," Laughlin says. "We're even working on an update."

Present

There was one unfortunate timing issue, though. Just before the book was published, astronomers discovered that the

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>
> *- Fred Adams*

expansion of the universe is accelerating as a result of dark energy. "It's not in it," says Laughlin. "Our book describes the long-term future of a universe without dark energy."

Over the past ten years, the concept of accelerating expansion has become an integral part of the concordance model of cosmology, and it's clear that dark energy, whatever its true nature, is a major factor in determining the distant evolution of the universe. In fact, it's one of the reasons why Laughlin and Adams are thinking about an update of the book.

On the other hand, says Laughlin, very little of the content of the first edition has been superseded. For example, some events, like the eventual clustering of black holes, won't happen in an accelerating universe. And many other things, especially those happening to individual objects, will occur all the same, albeit under black skies, since the ever-increasing cosmic expansion rate will eventually push other objects beyond the observing horizon of almost any point in space.

However, other parts of the book will benefit from an updated edition. "Extrasolar planets have been discovered, our view of galactic dynamics has improved, and in many cases, more interesting detail has surfaced. We now have a much richer story to tell," says Laughlin.

Still, scientific mysteries about the long-range forecast of the universe remain. Dark energy, for one, and according to Rees, another is the problem of the protons.

Protons – the positively charged particles in atomic nuclei – appear to be fundamentally stable. But, explains Laughlin, according to the standard model of

RED GIANT The end of the Earth will come long before the end of the universe

physical cosmology, in the very long run, protons must decay into other particles. The thing is: No one knows what the half-life (the time after which half of a given collection of protons has decayed) of a proton is, although experiments suggest it must be over 10^{35} years.

How can scientists begin to think about the long-term future of the universe if the stability of matter, or the behavior of space-time, are in question? Laughlin concedes that the topic is indeed somehow "divorced from the scientific method," in the sense that you can't carry out experiments to confirm or refute your theories about what will happen in the extremely distant future. "These ideas always reflect our current understanding of physics," he says.

But trying to predict the death of the universe may also provide scientists with a better understanding of the world we live in.

And that's why Adams and Laughlin are still at it today.

Future

The collaboration between the two physicists has been so successful, says

Adams, because "we're both the same *and* different in just the right way." Adams has a solid background in the analytical formulation of a problem – "He can easily turn any idea or question into an equation," says Laughlin – while Laughlin is good at the numerical, "number-crunching" approach to a problem, such as running huge computer simulations to study the possible outcomes of processes like merging stars or evaporating galaxies.

"It's a good combination," says Adams. "In astrophysics, you always need both approaches. You need the analytical model to understand what's going on and what you're doing. You need the numerical model to know what the answer is."

"It's not just that we had this different skill sets," says Laughlin. "We just both like to think about these kind of things. Moreover, we're both able to accept a good argument. We have no problem whatsoever arguing about each other's viewpoints."

While writing the book, Adams says it was initially a challenge to develop a single authorial 'voice.' "But it worked out very well. We jointly wrote chapter 1, I did chapters 2 and 3, Greg wrote chapter 4, and so forth." For both scientists, it was their first experience in writing a popular-level book. "We edited each other's texts, and we had a good agent, too," says Laughlin. "It was fun."

Over the years, Adams and Laughlin have become very close friends, in addition to being good colleagues. "I have other collaborations with other scientists," he says, "but they're all very different. Of course we worked closer together while Greg was here in Michigan, but even now he's back in California, we exchange lots of email, we extensively talk on the phone once per month or so, and we meet in person at least every year. If I have business in California, I'll stay at his place and sleep on the couch. Also, some of his stuff is still in my Michigan basement."

As they ponder their futures, separated by half a continent, Adams and Laughlin no longer discuss the future of the universe over morning coffee. Both are busy working on many other interesting topics – sometimes together, as in the case of the dynamical stability of extrasolar planetary systems – but often apart. Laughlin is hopeful that "this will change again in the near future." Adams agrees. "We've certainly not lost interest," he says. After all, "My non-major course on the long-range forecast of the universe is still very popular. The "Death of the Universe" talk won't die."

Nor will the fruitful collaboration on this topic between the two scientists. At least, not in the foreseeable future.