Terraforming from Science Fiction to Science

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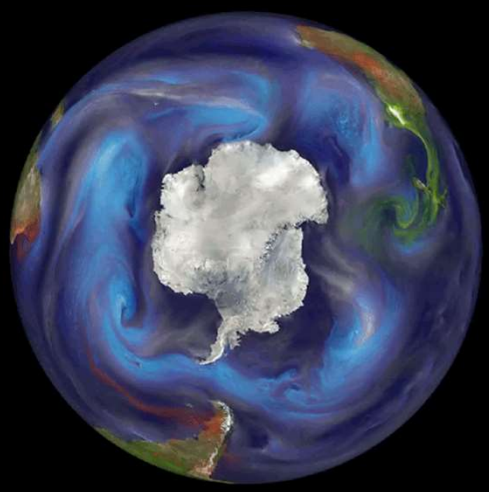

About Me

- PhD Candidate in English and Science and Technology Studies at UC Davis
- I study feedback loops between science and the arts
- Dissertation title: *Speculative Planetology: Science, Culture, and the Making of Model Worlds*
- My specialties
  - Science fiction literature and media
  - History and culture of climate modeling and planetary science

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A little about me: I'm a PhD candidate in English and Science and Technology Studies at UC Davis
In my work, I study feedbacks between ideas and stories, especially in science fiction and science. The title of my dissertation is Speculative Planetology: Science, Culture, and the Making of Model Worlds. So a lot of my research is about the history of climate science and planetary science, and how that history has been influenced by different non-scientific parts of culture, like art and literature. The main takeaway from my dissertation project has been that the work of what we might call worldbuilding is a collective practice: human cultures make sense of Earth and interpret how Earth works in many different ways. AND, the imagination plays a really big role in enabling us to think at the planetary scale at all. [So my dissertation is partly about showing that something like the swirling image on the left there is BOTH a visualization of a climate model from NASA, and also an act of worldbuilding that is the product of many different kinds of labor, not just scientific labor.

Two case studies

- Terraforming narratives interacted with science and technology
- The interactions created new ways of thinking about environmental and technological futures
- **Takeaway**: the stories we tell about fictional scenarios, even about terraforming imaginary worlds, help to decide what happens to our own world

Today I'm going to present two cases as examples. These are moments where terraforming narratives in the arts interacted with scientific approaches planetary thinking. In both of these examples, terraforming narratives helped to create new ways of thinking about environmental and technological futures. My goal is to convince you all that the stories we tell about fictional scenarios, even about terraforming imaginary worlds, matter to what happens to our own world.

Case 1:
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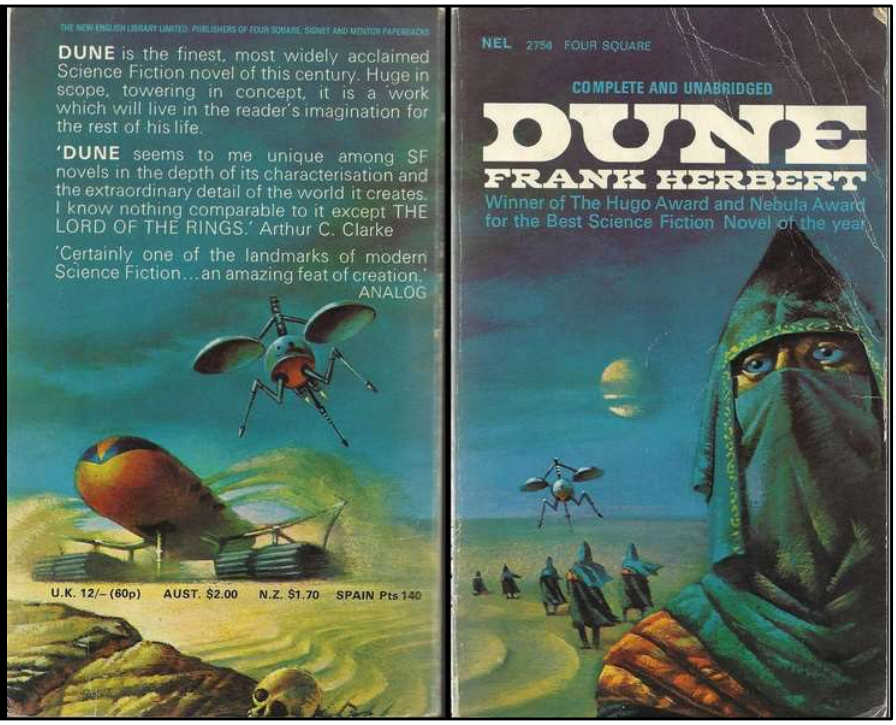
Dune (1965), ecology and planetary science



When it comes to science fiction that is important to the history of climate science, Frank Herbert's 1965 novel *Dune* is one of the most significant examples. It is also a novel about terraforming that is set on an imaginary world. I'm not going to assume that everyone has read *Dune*, but I'm sure at least some of you have. In this case study, I will show you how *Dune* has become a touchstone for climate and planetary scientists: using examples from their blogs, forum posts, and publications. Then I will lay down the groundwork for a theory about why *Dune* is so important to scientists, by tracking what the author Frank Herbert did to write the novel.

Case 2:
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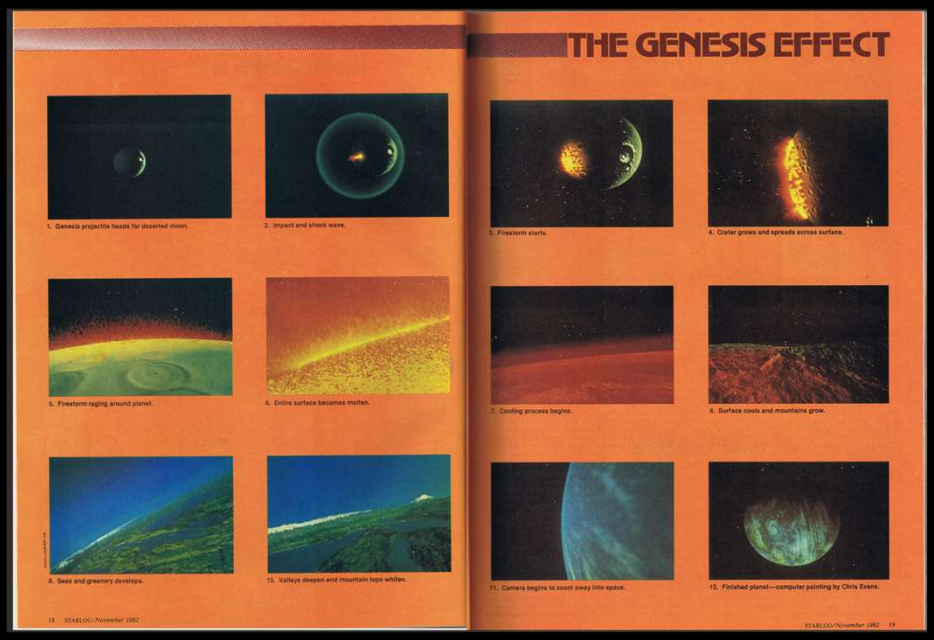
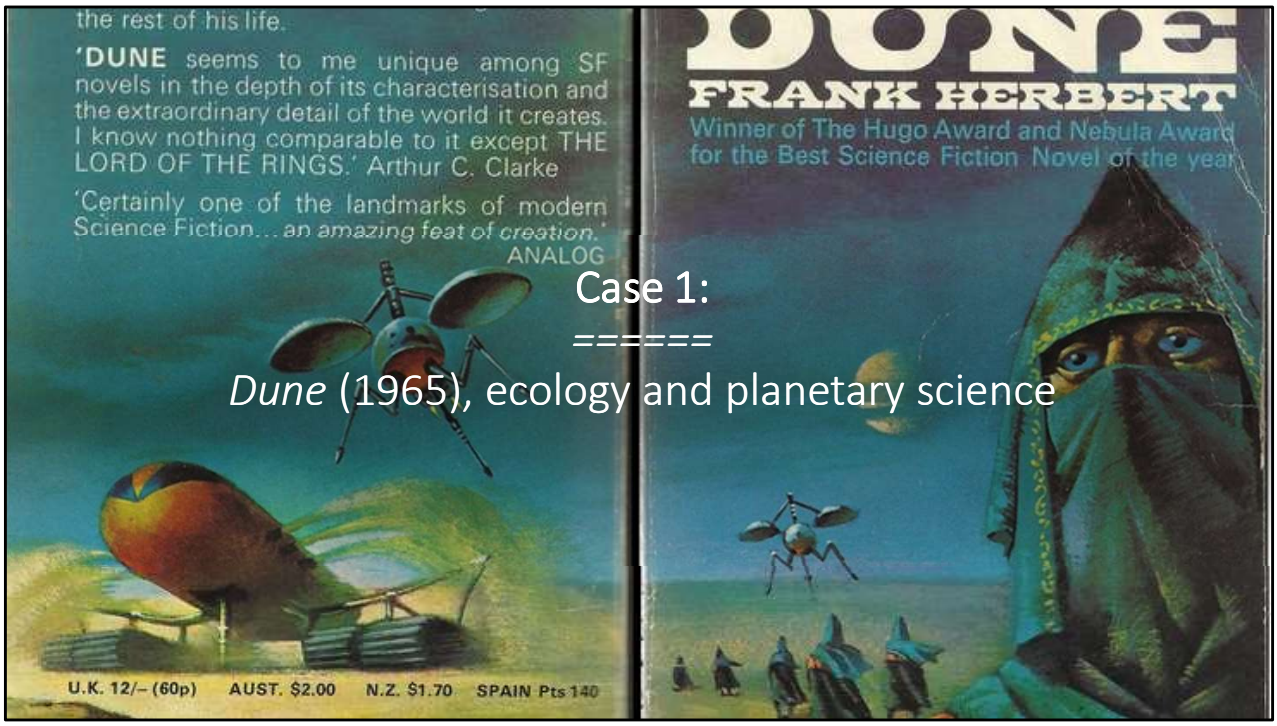
"The Genesis Effect" (1982) and particle systems



The second example I will present is from the film Star Trek II: The Wrath of Khan, which becomes a terraforming story when a scientist in the movie invents a bomb that can convert any lump of matter into a living world. Here, I focus on the computer science community and particularly on the computer graphics engineers who created the special effects for the film. I will show you how the storyline of the Wrath of Khan got mixed up in the creation of particle systems, which lead to new ways of thinking about planets and about simulated life.



Case 1:
======
Dune (1965), ecology and planetary science

Before I make my argument about *Dune,* I want to give a very brief, simplified plot summary for people who haven't read the book.

Dune is the story of Paul, a young man with amazing powers of observation that allow him to see the future. The novel traces how he goes from being a dispossessed ducal heir stranded on a desert planet to becoming the prophet of the Fremen. The Fremen are indigenous desert dwellers who, under Paul's leadership, form a guerrilla army and take over the galactic empire.

One of the major plot points in the novel involves the terraforming of the planet Arrakis. The Fremen are secretly involved in a centuries-long science project where they are trying to make their desert world – which is literally almost without water – into a garden world with open running water and plants. In the story, Herbert uses a kind of world building that was pretty new in the early 1960s. Almost everything about the planet Arrakis can be explained by the fact that it doesn't have enough water. For example, in one scene, a leader of the Fremen spits on the table in front of the Duke. The Duke is angry until someone explains that sacrificing water is a great sign of respect on this planet.

How Climate Scientists Talk about Science Fiction (Especially *Dune)*

So as I suggested, the first thing I want to do is prove to you that speculative fiction is important to climate and planetary scientists.

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Habitable Zone Limits for Dry Planets

Yutaka Abe,[1] Ayako Abe-Ouchi,[2] Norman H. Sleep,[3] and Kevin J. Zahnle[4]

Abstract

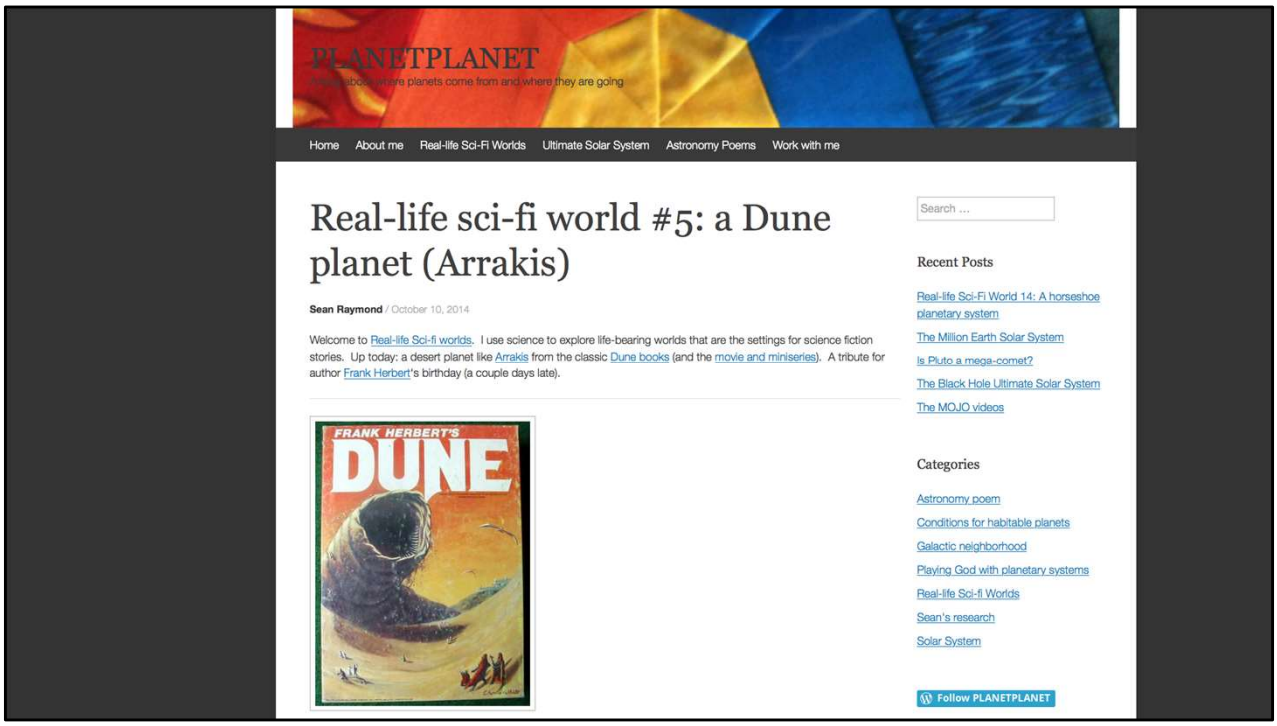
Most discussion of habitable planets has focused on Earth-like planets with globally abundant liquid
an "aqua planet" like Earth, the surface freezes if far from its sun, and the water vapor greenhouse
away if too close. Here we show that "land planets" (desert worlds with limited surface water)
habitable zones than aqua planets. For planets at the inner edge of the habitable zone, a land plan

Recent astrobiology work on the possible distance from the sun that a planet could sustain life has cited Dune explicitly. Here is an article, entitled "Habitable Zone Limits for Dry Planets," published in the journal Astrobiology. The scientific intervention of this article is that the authors used a climate model to rethink the likelihood of finding life on different kinds of planets.

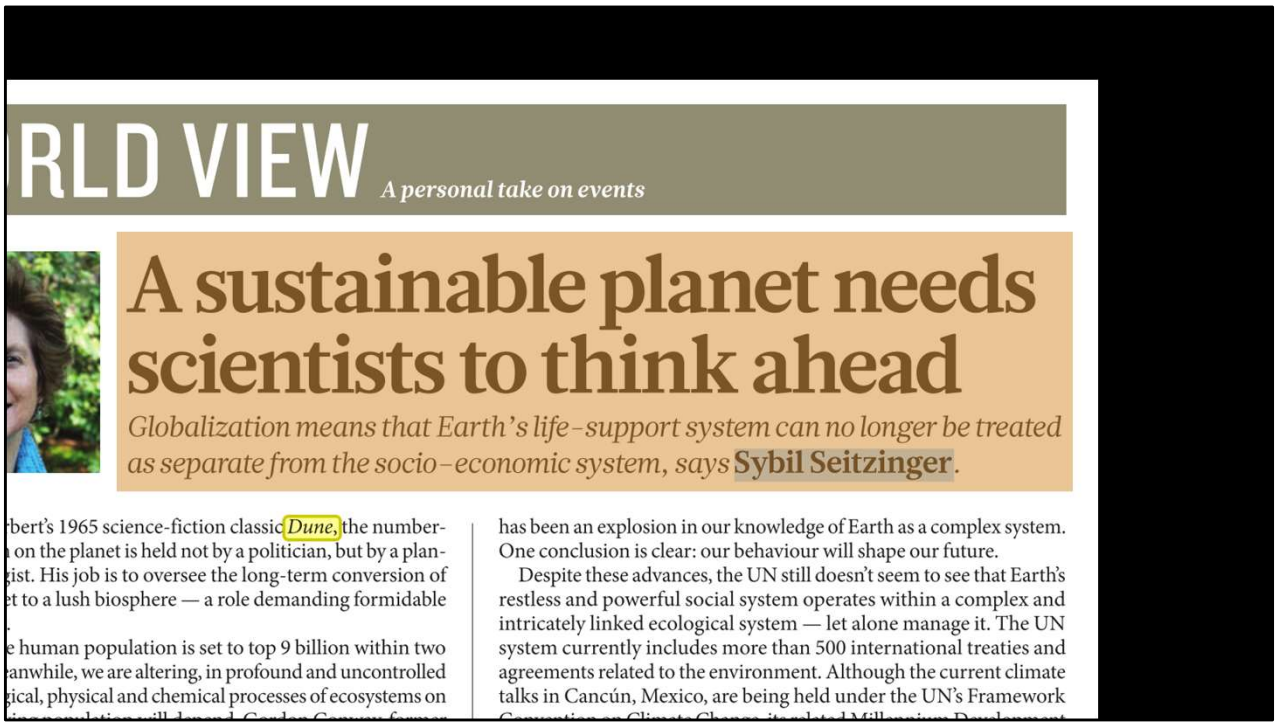
"Habitable Zone Limits for Dry Planets"
by Abe et. al

"We can imagine another kind of habitable planet that has only a small amount of water and no oceans; it might be covered by vast dry deserts, but it might also have locally abundant water. We call such a dry planet a ''land planet.'' The fictional planet known as Arrakis or Dune (*Dune*, Herbert, 1965) provides an exceptionally well-developed example of a habitable land planet. In its particulars, Dune resembles a bigger, warmer Mars with a breathable oxygen atmosphere. Like Mars, Dune is depicted as a parched desert planet, but there are signs that water flowed in the prehistoric past. Dune has small water ice caps at the poles and more extensive deep polar aquifers. The tropics are exceedingly dry, but the polar regions are cool enough and moist enough to have morning dew" (443).

In the article, the authors praise Dune for what they call "an exceptionally well-developed example of a habitable land planet."
Importantly, they open with the phrase "We can imagine another kind of habitable planet…" The signal "we can imagine" is to tell readers that though we are still in the realm of science, the scientists are going to use a technique of speculation to explain the results of their model.
They get substantially into the details about the planet as well, particularly making note of:
-the planets' polar ice caps.
-"signs that water flowed in the prehistoric past."
-"the polar regions are cool enough and moist enough to have morning dew"
Each of these points is mentioned in just a few brief sentences in the novel. As English instructors, my colleagues and I are always hoping to get students to use this level of detailed evidence in their writing.



Citing this article as well as *Dune* and several sequels, here's astrophysicist Sean Raymond adding to the knowledge of Arrakis by working out the likely particulars of Dune's proximity to its star, and what will happen when Canopus goes supernova. Since the Abe et al. paper, astronomers actually call this kind of planet a "*Dune* planet". No longer just a title of a novel, a Dune planet has become a term with a specific scientific definition in this field.



RLD VIEW *A personal take on events*

A sustainable planet needs scientists to think ahead

Globalization means that Earth's life-support system can no longer be treated as separate from the socio-economic system, says **Sybil Seitzinger**.

rbert's 1965 science-fiction classic *Dune*, the number- on the planet is held not by a politician, but by a plan- gist. His job is to oversee the long-term conversion of t to a lush biosphere — a role demanding formidable

e human population is set to top 9 billion within two anwhile, we are altering, in profound and uncontrolled gical, physical and chemical processes of ecosystems on

has been an explosion in our knowledge of Earth as a complex system. One conclusion is clear: our behaviour will shape our future.

Despite these advances, the UN still doesn't seem to see that Earth's restless and powerful social system operates within a complex and intricately linked ecological system — let alone manage it. The UN system currently includes more than 500 international treaties and agreements related to the environment. Although the current climate talks in Cancún, Mexico, are being held under the UN's Framework

However, it's not just scientists who work on outer space that seem to find science fiction in general, and Dune in particular, to be a touchstone. For example, the climate scientist Sybil Seitzinger writes here in the journal *Nature* about how, in order to tackle the world's climate problems, we need to have a planetary ecologist, modeled on Liet Kynes, the imperial planetologist in *Dune*.

"SFnal" climate science?

I do take advantage of a somewhat SFnal view of the universe in doing my research. That is, I'm trying to understand, say, the earth's climate. That's only one place with one particular set of conditions. What (the SF-fan in me asks) would it be like if the earth rotated much faster, more slowly, if the sun produced less UV (hence less ozone on earth, hence less greenhouse effect in the stratosphere, hence …?), if the earth were farther away/closer in, and so on. I can't say that it's resulted in any journal articles that I wouldn't have written anyhow, but it does make it easier for me to, say, read paleoclimate papers (the earth did rotate faster in the past, sea level has been much higher and lower than present, …)

Robert Grumbine, *More Grumbine Science* blog

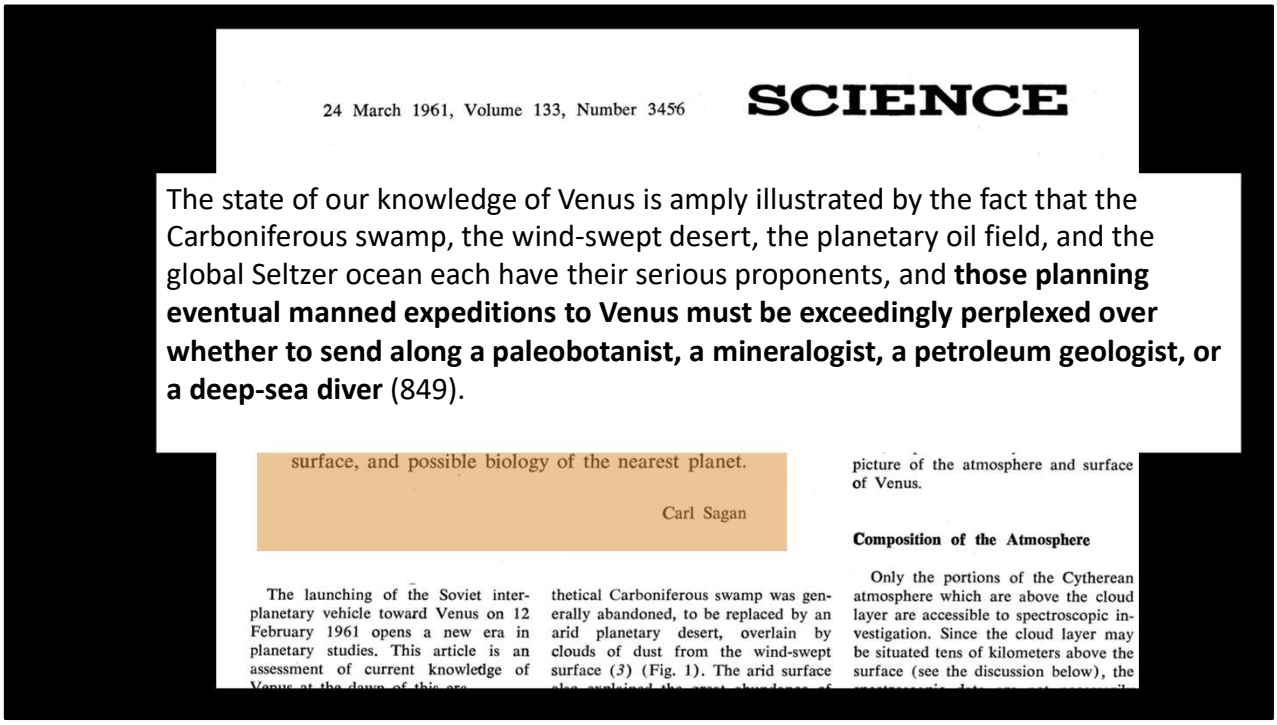
Robert Grumbine, climate modeler, oceanographer, writes in his blog about the relationship between "Science fiction and science."
"I do take advantage of a somewhat SFnal view of the universe in doing my research," he writes. "That is, I'm trying to understand, say, the earth's climate. That's only one place with one particular set of conditions. What (the SF-fan in me asks) would it be like if the earth rotated much faster, more slowly, if the sun produced less UV (hence less ozone on earth, hence less greenhouse effect in the stratosphere, hence …?), if the earth were farther away/closer in, and so on."
What, Grumbine asks here, would it be like if planetary conditions were other than they are? This is the same kind of speculative thinking that we saw in the Abe et al paper when they started the paragraph about Dune with the phrase "We can imagine." Grumbine is emphasizing that in order to integrate ideas about how planetary climate can change, he uses a skill that is similar to the kind of worldbuilding speculation we use when reading and writing science fiction.

An "sfnal" way of thinking

- Imbrication of history of climate modeling with history of science fiction
- Standard model of climate has few requirements:
  - Top of atmosphere energy balance
  - Convection model of energy transfer
- This was surprisingly difficult for early climate science to get right*

*credit due to R.T. Pierrehumbert's Tyndall lecture for this observation

In general, we can also say that the history of climate modeling is more closely imbricated with the history of science fiction than we might initially think. For example, the "standard model," to adapt a term from physics, of planetary climate involves a few key insights. First, that the atmosphere needs to be imagined to have layers—at the very least, in order to get what we call the greenhouse effect, you have to start by balancing the energy inputs and outputs (that is, solar radiation on its way in and mainly infrared radiation on its way out) from the top of the atmosphere, not from the earth's crust. Second, you need to use a model of atmospheric convection to describe how heat is transported around inside that planetary envelope. This was surprisingly difficult for early climate scientists to get all of these ingredients into one model. The very first person to manage this wasn't a meteorologist, and they weren't doing it with respect to Earth.



24 March 1961, Volume 133, Number 3456 **SCIENCE**

The state of our knowledge of Venus is amply illustrated by the fact that the Carboniferous swamp, the wind-swept desert, the planetary oil field, and the global Seltzer ocean each have their serious proponents, and **those planning eventual manned expeditions to Venus must be exceedingly perplexed over whether to send along a paleobotanist, a mineralogist, a petroleum geologist, or a deep-sea diver** (849).

surface, and possible biology of the nearest planet.

Carl Sagan

The launching of the Soviet interplanetary vehicle toward Venus on 12 February 1961 opens a new era in planetary studies. This article is an assessment of current knowledge of

thetical Carboniferous swamp was generally abandoned, to be replaced by an arid planetary desert, overlain by clouds of dust from the wind-swept surface (*3*) (Fig. 1). The arid surface

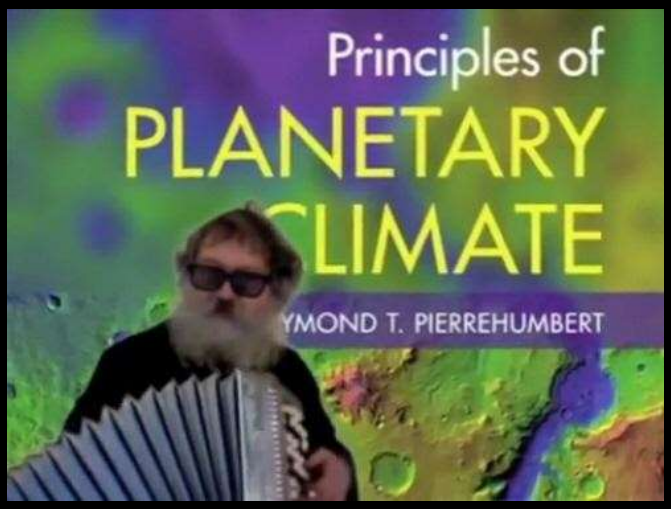
picture of the atmosphere and surface of Venus.

Composition of the Atmosphere

Only the portions of the Cytherean atmosphere which are above the cloud layer are accessible to spectroscopic investigation. Since the cloud layer may be situated tens of kilometers above the surface (see the discussion below), the

It was actually a 27-year-old Carl Sagan who applied a radiative-convective model to Venus in order to determine its interior temperature.
A follow-up piece the next year by Sagan emphasized the science fictional way that he had been thinking about Venus: in a 1961 article entitled “The Planet Venus,” he theorized about Venus’ greenhouse effect and joked about science-fictional (and science fiction-like, but scientific) scenarios that had previously been imagined for Venus’ climate, including “a planetary oil field and a global seltzer ocean,” joking that “those planning eventual manned expeditions to Venus must be … perplexed over whether to send along a paleobotanist, a mineralogist, a petroleum geologist, or a deep-sea diver” (849).

Raymond T. Pierrehumbert



To give one final example of this kind of thinking, I'd like to look at an article by Raymond T Pierrehumbert, who has by far my favorite personality of any climate modeler. He recently moved from the University of Chicago to Oxford. The screenshot on the right is a still from a music video that Pierrhumbert made, playing the accordion with his own climate modeling textbook behind him.

"Science Fiction Atmospheres"

- R.T. Pierrehumbert
- *Bulletin of the American Meteorological Society,* May 2005

This is what Pierrehumbert has to say about *Dune* in a piece for the Bulletin of American Meteorological Science.

the ground. But how is the aquifer recharged if it never rains? My best guess is that Dune is a dying world, with slow leakage of water into an atmosphere that is becoming gradually warmer on account of the water vapor greenhouse effect. A word of warning to those Dune scientists to wish to re-engineer the climate to bring on rain and surface water: if they succeed, they will almost certainly precipitate a runaway greenhouse. If Dune is already in a habitable temperature range without much water vapor greenhouse effect, introducing an ocean is likely to be fatal.

Dune's science fiction atmosphere

Pierrehumbert, 2005

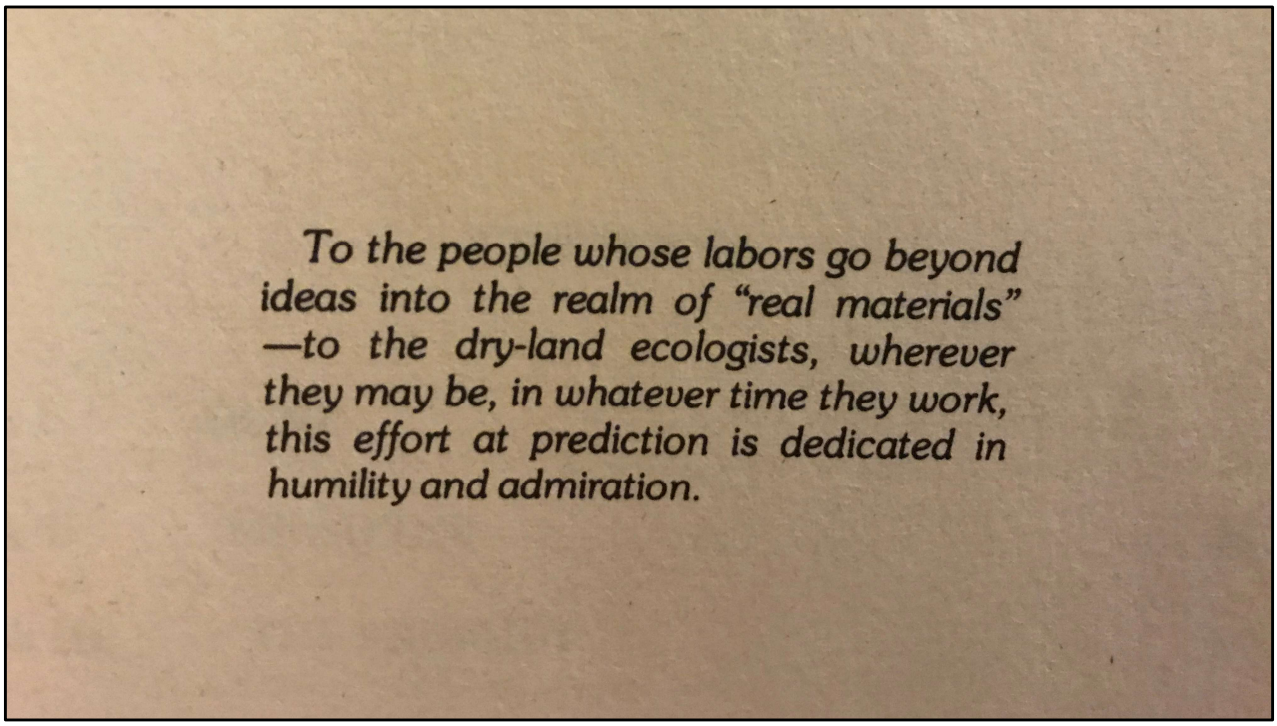
"How is the aquifer recharged if it never rains?" Pierrehumbert worries. "My best guess is that Dune is a dying world, with slow leakage of water into an atmosphere that is becoming gradually warmer on account of the water vapor greenhouse effect." He warns that the scientists in the novel who are trying to terraform the planet are making a dangerous mistake: if it is already so hot on the planet without much water vapor, it will likely become a runaway greenhouse like Venus if they manage to create an ocean. In this piece, Pierrehumbert uses the occasion of science fiction stories to show off the climate modeler's mentality that Grumbine described as "SFnal."

Why is *Dune* so important to planetary scientists?

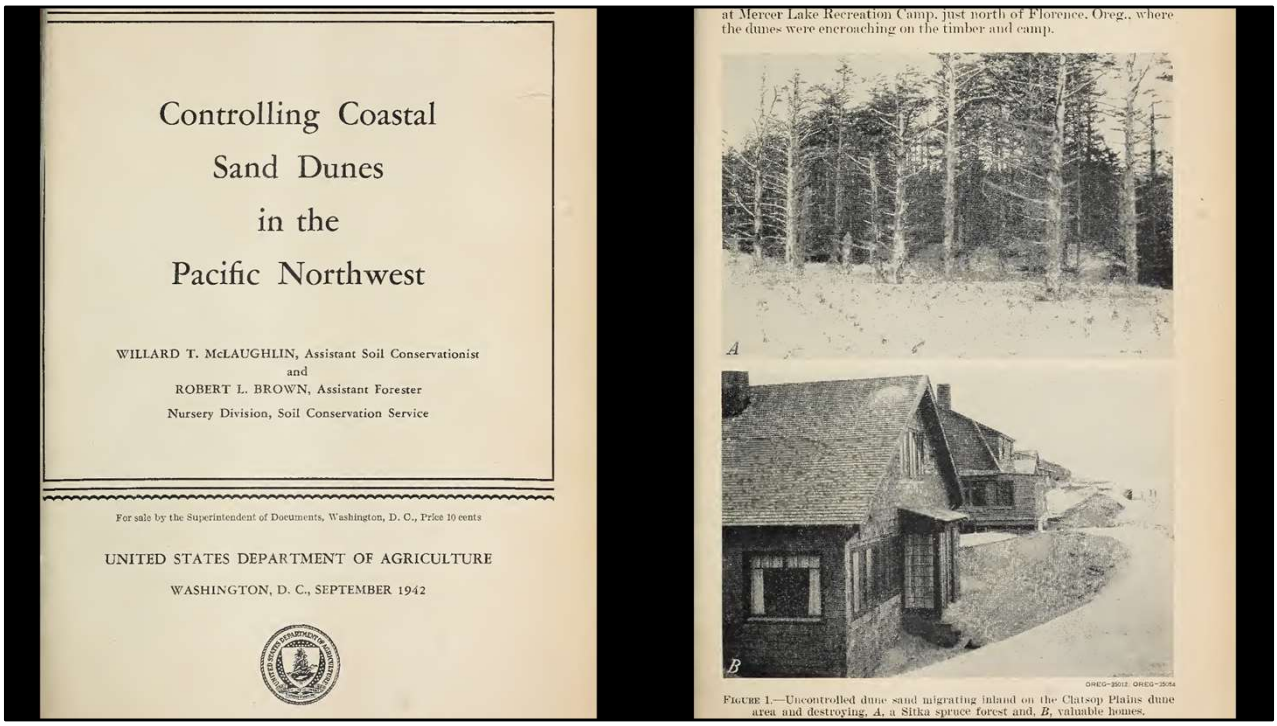
- Feedback loop:
- We've seen planetary scientists interested in science fiction
  - Because of the way that its thinking mirrors/supplements scientific planetary thinking
  - A lot of *Dune* examples
- Obviously, science fiction authors are also really interested in science.
  - How did Frank Herbert transform the science of his own moment to get *Dune?*

So I hope that I've managed to convince you that planetary science is very invested in science fiction, and not just in being fans of science fiction. Rather, at least a good number of planetary and climate scientists find that science fiction shares a way of thinking that is also part of planetary science. Secondly, they find that the way science fiction works, being specific about the experiences of being on a planet, is an important supplement to more technical, calculative approaches to studying planets.

I've also shown you that *Dune* is a touchstone in these conversations. When *Dune* was published, climate science was still in its infancy, and planetary science about planets other than earth was just starting to become an interdisciplinary field. What I want to argue next, is that the moves that Frank Herbert made in telling this terraforming story were super important because they mirror the moves that needed to be made in order to establish the field of planetary and climate science. To understand this, let's look at how Frank Herbert was influenced by the science of his own moment.


To the people whose labors go beyond ideas into the realm of "real materials" —to the dry-land ecologists, wherever they may be, in whatever time they work, this effort at prediction is dedicated in humility and admiration.

This is the dedication of the novel.
To the people whose labors go beyond ideas into the realm of "real materials"—to the dry-land ecologists, wherever they may be, in whatever time they work, this effort at prediction is dedicated in humility and admiration.
Why did Herbert dedicate *Dune* to the dry land ecologists, with (as he says) humility and admiration? To me this dedication indicates how important Herbert's experiences with local ecology in Oregon Dunes were to his writing of the novel. I'll tell you the story.



Controlling Coastal
Sand Dunes
in the
Pacific Northwest

WILLARD T. McLAUGHLIN, Assistant Soil Conservationist
and
ROBERT L. BROWN, Assistant Forester
Nursery Division, Soil Conservation Service

For sale by the Superintendent of Documents, Washington, D. C., Price 10 cents

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C., SEPTEMBER 1942

at Mercer Lake Recreation Camp, just north of Florence, Oreg., where the dunes were encroaching on the timber and camp.

A

B

OREG-25012, OREG-25054

FIGURE 1.—Uncontrolled dune sand migrating inland on the Clatsop Plains dune area and destroying, *A*, a Sitka spruce forest and, *B*, valuable homes.

In 1957, Frank Herbert, then a journalist and modestly successful science fiction author, had traveled to Florence, Oregon to report on a United States Department of Agriculture project to stabilize sand dunes that were migrating across a highway. In the words of literary biographer Tim O'Reilly, Herbert "became fascinated by sand dunes—the irresistible way they move, swallowing roads, houses, and on occasion entire towns." Herbert "imagined an entire planet that had been taken over by sand dunes, and an ecologist faced with the task of reclaiming it" (ch. 3). I found this and the following few images in a United States Department of Agriculture publication that is illustrating the Florence Dune encroachment and the project they undertook to control the dunes. The publication is from several years before Frank Herbert would visit, but it illustrates the ecological theory of the time.

OREG-35162

FIGURE 16.—A field the first year after planting to European beachgrass. The planting stock, projecting about 8 inches above the sand level, decreases the wind velocity and causes sand deposition if the spacing is correct and the planting is maintained.

Set 200 centuries in our future, *Dune* extends the Oregon Dune project, envisioning the dunes creeping inexorably across an entire planet over the course of deep time. The terraforming process that the ecologist Kynes is implementing on the desert planet Arrakis mirrors the Oregon Dune stabilization project and the theory of ecological succession that was cutting edge in the middle of the 20th century:

Terraforming

"Our first goal on Arrakis," his father said, "is grassland provinces. We will start with these mutated poverty grasses. When we have moisture locked in grasslands, we'll move on to start upland forests, then a few open bodies of water—small at first—and situated along lines of prevailing winds with windtrap moisture precipitators spaced in the lines to recapture what the wind steals. We must create a true sirocco—a moist wind—but we will never get away from the necessity for windtraps."

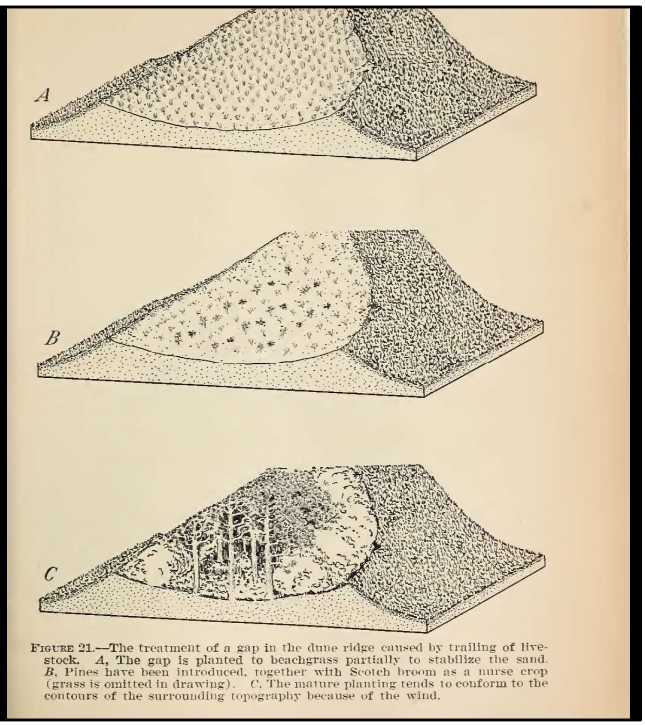
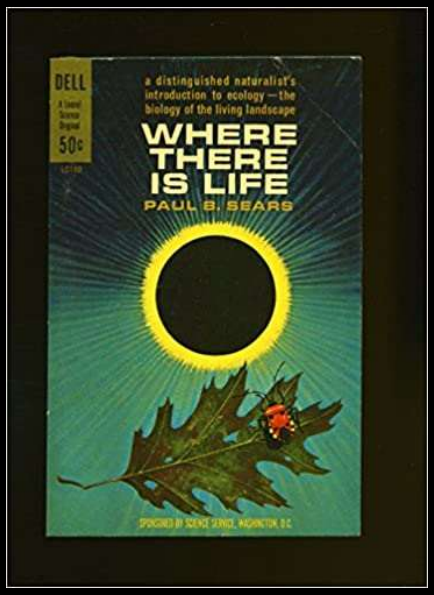


FIGURE 21.—The treatment of a gap in the dune ridge caused by trailing of livestock. *A*, The gap is planted to beachgrass partially to stabilize the sand. *B*, Pines have been introduced, together with Scotch broom as a nurse crop (grass is omitted in drawing). *C*, The mature planting tends to conform to the contours of the surrounding topography because of the wind.

"Our first goal on Arrakis … is grassland provinces. We will start with these mutated poverty grasses. When we have moisture locked in grasslands, we'll move on to start upland forests, then a few open bodies of water" (5632-5640).

The specific terraforming process being enacted in the novel (which is almost exactly like what we see with the Oregon dunes) demonstrates an effort on Herbert's part to scale local working ecology up to a planetary size. This is made even more explicit if you look at the sources he drew on. Herbert claims to have read "over two hundred books as background for this novel," many of them about ecology. In his initial imagining of the novel, the ecologist Kynes was to be the main character, and in the finally-published version Herbert puts this direct quotation from ecologist Paul Sears in the character's mouth: "The highest function of ecology is the understanding of consequences" (Maker of Dune, 104).



Actually, this isn't the only thing that Herbert lifted from Sears' book. For all of *Dune's* impressive and visionary interweaving of ecological and cybernetic concerns, it is possible to identify nearly every ecologically oriented statement in the text as having its origin in a slim volume called *Where There is Life* by the ecologist Paul Sears. I have found nearly 20 examples of what are essentially direct quotations from this book in *Dune*. Frank Herbert adapts these materials by simply taking a phenomenon on a local scale, such as the Oregon dunes, and positing that same phenomenon at a planetary scale. Imagine that dunes aren't just overspilling a highway but the entire planet. Then imagine that we try to stop their progression just like we're doing in one town in Oregon. Here are three examples of times where Frank Herbert borrowed text from Sears.

In *Where There is Life*	In *Dune*
"Cowles saw how vegetation was largely **determined at first by raw physical forces**, then gradually **established itself** and at length **became a controlling influence** that tended […] to stabilize the earth's surface" (97).	Vegetation and animal changes will be **determined at first by the raw physical forces** we manipulate. As they **establish themselves**, though, our changes will **become controlling influences** in their own right (445).

In the next few slides, I used color to show how Frank Herbert re-used text from Paul Sear's book to create the terraforming story in Dune. Here we see a biographical sketch about a Chicago-based naturalist in Sears' book, and Herbert turns it into a pronouncement about what will happen when they terraform the whole planet of Arrakis.

In *Where There is Life*	In *Dune*
This assurance seems to satisfy many who forget that, beyond a certain critical point, freedom diminishes as numbers increase within a finite space. This is as true of humans on a continent as of gas molecules in a sealed flask (23).	Beyond a critical point within a finite space, freedom diminishes as numbers increase. This is as true of humans in the finite space of a planetary ecosystem as it is of gas molecules in a sealed flask (797).

Here's another example– you can see that Herbert re-uses almost the entire quotation. [Read it out loud]

In *Where There is Life*	In *Dune*
This assurance seems to satisfy many who forget that, beyond a certain critical point, freedom diminishes as numbers increase within a finite space. This is as true of humans on a continent as of gas molecules in a sealed flask (23).	Beyond a critical point within a finite space, freedom diminishes as numbers increase. This is as true of humans in the finite space of a planetary ecosystem as it is of gas molecules in a sealed flask (797).

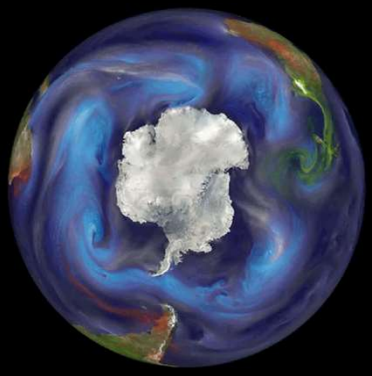
The only difference between the two, which I've highlighted in blue here, is that where Sears talked about "humans on a continent," Herbert talked about "a planetary ecosystem."

In *Where There is Life*	In *Dune*
"The Crusades, which had become a **system of mutual pillage and extortion**, also helped create great mercantile and shipping cities in the north of Italy" (194).	"The historical **system of mutual pillage and extortion** stops here on Arrakis," his father said.

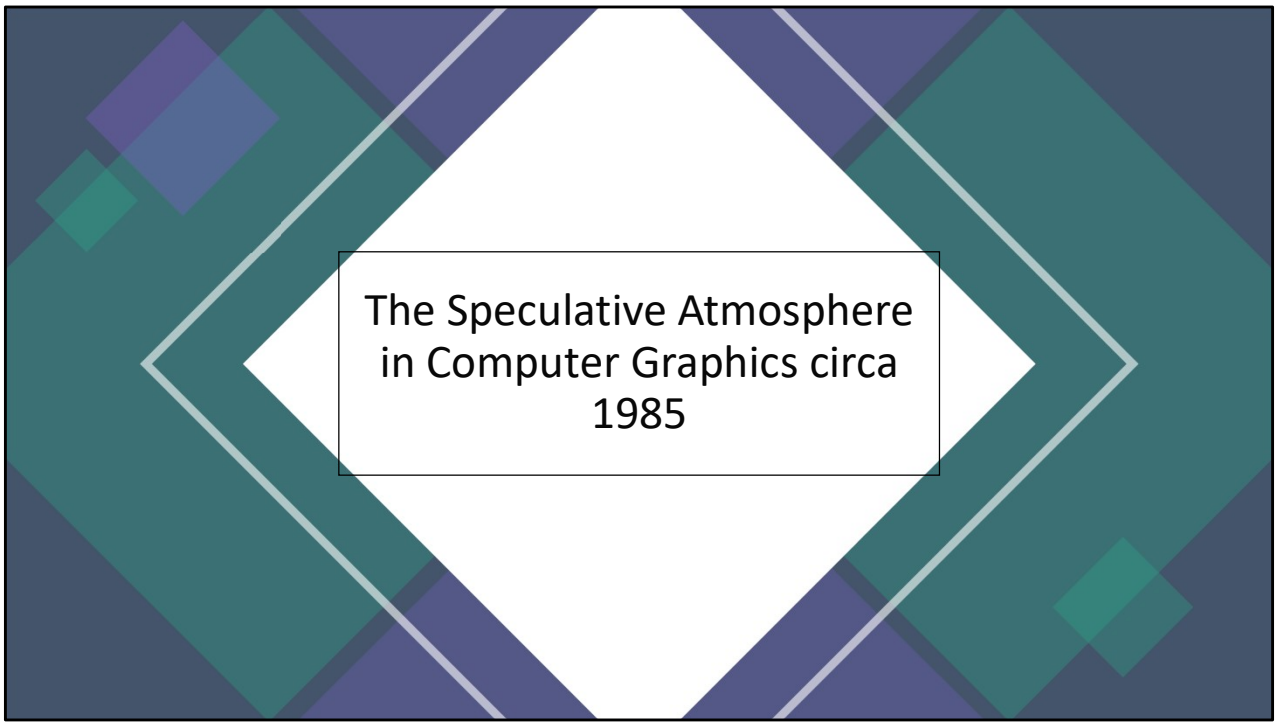
And here again, we see Herbert borrowing part of a quotation from sears, but where Sears is talking about the north of Italy, Herbert has transformed the statement to be about the entire planet of Arrakis.

Scaling up

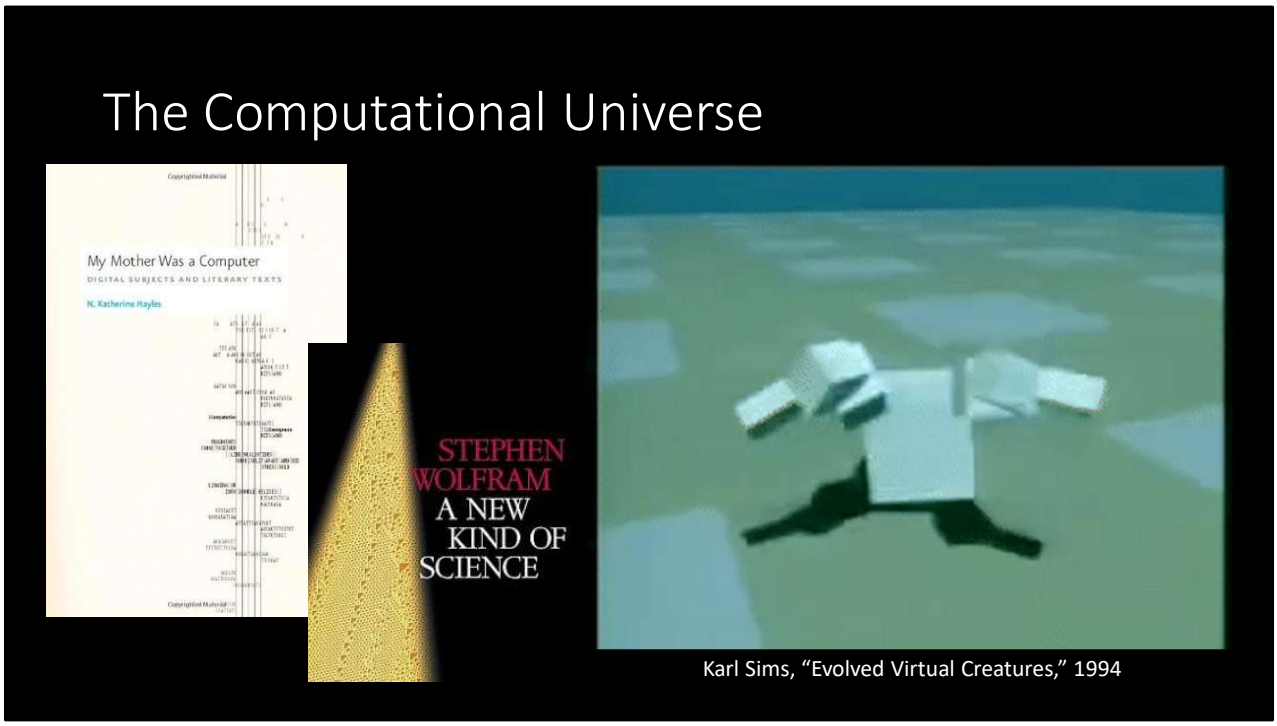
- A planet has "climates" → a planet has a "climate"
- Working ecology (like the USDA dune project) → planetary ecology



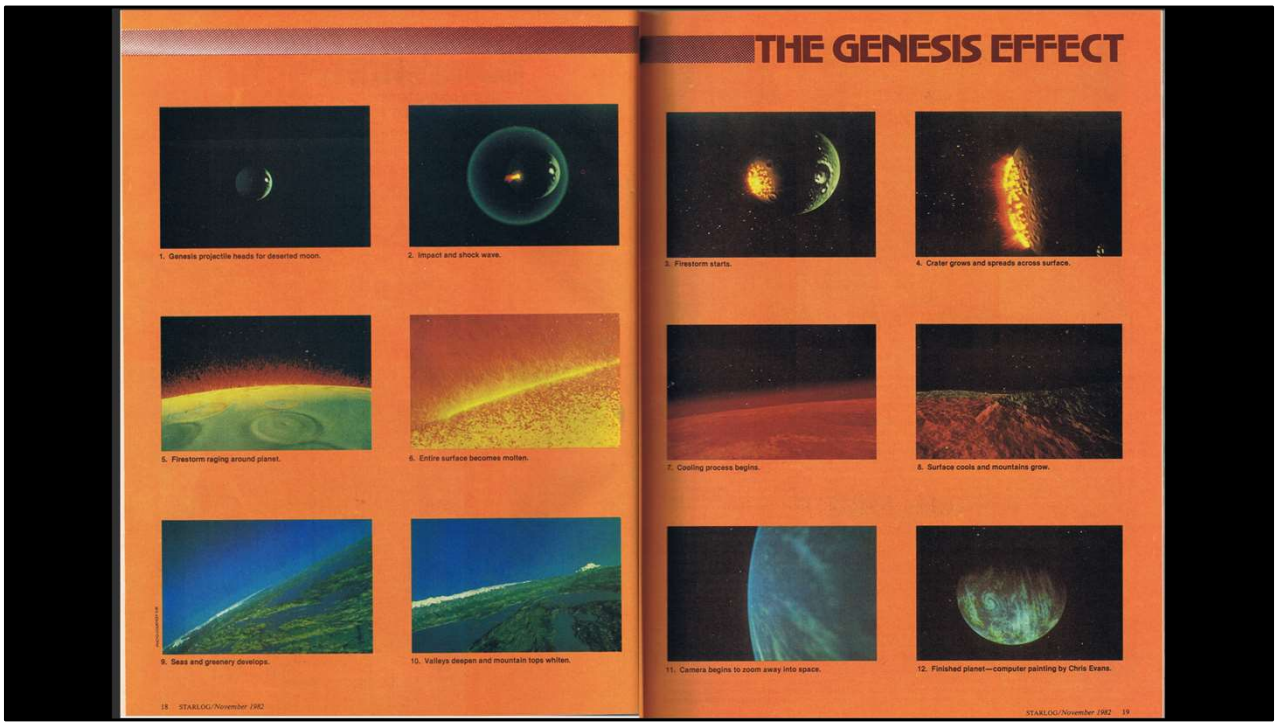
Shifting these local ecological phenomena up to planetary scale allowed a simple kind of mid-century working ecology to take on the proportions of planetary world building that would allow Dune to inspire scientists and fans alike to build their own models of imaginary worlds. Take, for example, the word climate as applied to a whole planet. It emerged at some point in the latter half of the 20th century, but at the time that Sears was writing there were only "climates"—a local or bioregional category but not one that could characterize the atmosphere of the whole world. For Sears, a climate is the weather and seasonal patterns of a given place. Frank Herbert posits something like the version of planetary climate that we're familiar with—the singular term applied to the whole of Arrakis. But you can see how that's just something that emerges from scaling a bioregional climate up to fill a whole planet. There's a tremendous power to this method, and as I argue in the written version of this piece, the moves that planetary science makes to scale ecology up to the planetary scale are often the same kinds of moves that planetary science fiction makes. This means suturing gaps between pieces of data at a smaller scale, ensuring that equations and flows connect up correctly at the planetary scale instead.



My goal in the next part of this presentation is to show a moment in history where a speculative representation of terraforming a planet helped usher in a new understanding of nature. To do so, I'll be talking about a speculative atmosphere in computer graphics in the early 1980s. This is kind of a pun: on the one hand, I'm tracking what I think of as a speculative orientation amongst the artists, researchers, and practitioners in the field of computer graphics in this period. On the other hand, that speculative *intellectual* atmosphere happens to have been full of computer generated imagery, or CGI, of simulated planetary atmospheres.



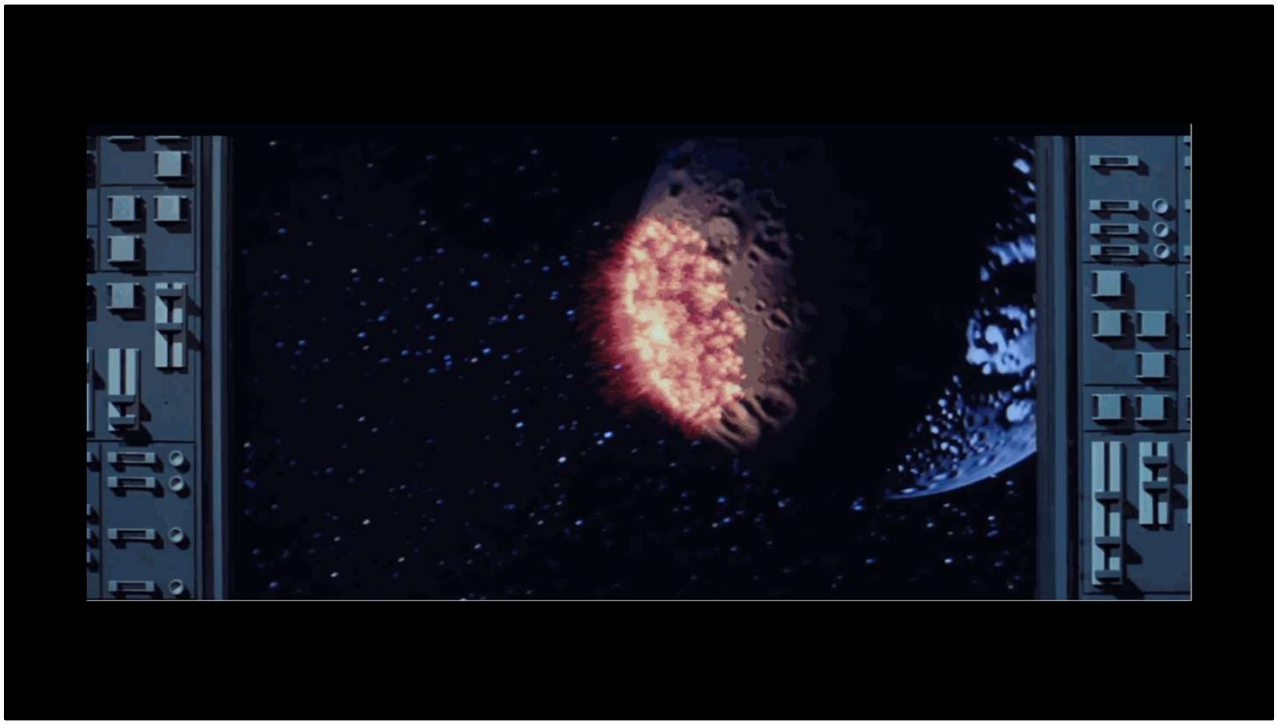
The new concept of nature I'm referring to is what Kate Hayles calls the computational universe. This is the idea that computation doesn't just simulate real-world phenomena, but that there is a mathematics that undergirds and generates all complex phenomena, both analog and digital. The computational universe is incredibly important to why the sciences of simulation are seen as being able to explain living systems– if simulated systems are themselves already alive, then simulations can count as experiments on life. The idea that graphically rendered computer simulations are equivalent to living systems was not inevitable. I want to tell you about a moment in the 1980s where the idea of living worlds simulated on a computer got a new kind of traction.



The year was 1982. The image you see behind me is from Starlog, the science fiction fan magazine, and it is a representation of a sequence of computer generated imagery, or CGI, in print form.
The genesis effect is an animation made by computer graphics engineers in Lucasfilm's research and development department. These guys would go on to found Pixar like four years later. [click] The cinematographic reason for this wonder of computer graphics was Star Trek's The Wrath of Khan, directed by Nicholas Meyer for Paramount and released in 1982. In the film, in case you haven't seen it, an ungracefully middle-aged Captain Kirk and friends reassemble after years of elder statesmanship in Starfleet, not expecting that they'll need to run a surprise mission. Khan, the antagonist, is trying to get revenge on Kirk for some earlier slight by stealing a technology called the genesis device. The genesis device was built to be a tool of creation, but it has the unfortunate property that it can also destroy all life on a planet if used in the wrong place. Khan is desperate to get his hands on it, and Kirk and the rest of the crew are desperate to stop him.

But really, what's important here is the genesis effect itself, the kernel of speculation at the center of my story.

I'd like to play that clip one more time but with the sound turned off. The part I'm replaying was created by a team of computer graphics engineers at Lucasfilm, and it was the very first scene of completely computer generated imagery ever put on film. It had a lot of scientific and technical innovations in it, but the one that got the most attention, and that was published about, was the particle system. The particle system was invented by William Reeves specifically for this film sequence. Pay attention to the way that the fire looks here– it isn't animated by hand drawing, but is instead procedurally rendered as many tiny, glowing points with specific lifetimes and movement patterns. The fire is really a kind of swarm of particles each with their own programming. Other important parts of the animation are the fractals used to make the landscape of jagged rocks, and the slowly growing atmospheric haze of the planet.



It's hard to overstate the historical importance of this computer graphics sequence in the history of computer graphics. It felt, at the time, like a tremendous leap forward in terms of what computer-generated imagery could do. What I want to show you in the rest of this presentation is how the terraforming plot got mixed up into the computational processes that rendered the particle system, creating a new sense of belief in the idea of simulated living worlds.

The entire genesis sequence is actually CGI of CGI. The audience is supposedly seeing a simulation that the protagonists are themselves watching on a computer monitor. So this is not a simulation of a natural phenomenon, but a simulation of a simulation of one. In the story, in other words, Dr. Marcus is positioned not all that differently from the computer graphics engineers at Lucasfilm— she hasn't done the real life experiment, but she is presenting to the federation a simulation of what she calls "life from lifelessness," a reorganization of matter with "life generating results." There is an odd and compelling mirroring between what this image sequence was in the 1980s, and what it is in the fictional 23rd century. There is one major difference between this simulation as a part of our own world, and the fictional simulation in the storyline: in the Star Trek Universe, this simulation serves as Marcus' rhetorical proof of concept, showing the federation that the genesis effect is really possible without actually implementing it yet.

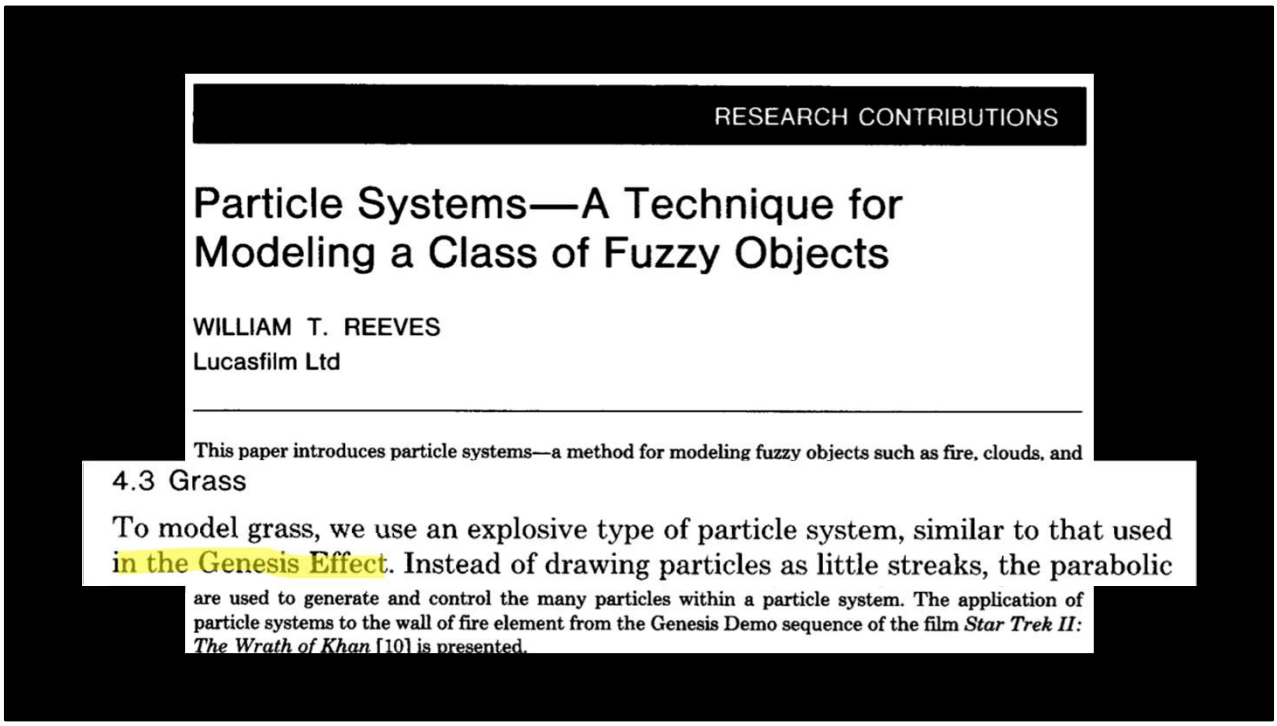
"Genesis effect"

DR MARCUS: "Stage Three will involve the process on a planetary scale. It is our intention to introduce the Genesis device into the pre-selected area of a lifeless space body, such a moon or other dead form. The device is delivered, instantaneously causing what we call the Genesis Effect. Matter is reorganized with life-generating results."

The Lucasfilm Computer Graphics Team

The computer graphics group of the Lucasfilm Computer Division, 1984 (L–R): Loren Carpenter, Bill Reeves, Ed Catmull (vice president, Computer Division), Alvy Ray Smith (director of computer graphics research), Rob Cook, John Lasseter, Eben Ostby, David Salesin, Craig Good, and Sam Leffler. Not pictured: David DiFrancesco, Tom Duff, Tom Porter.
Courtesy of Alvy Ray Smith

We can track this blurring by using the evidence of how language about the computer graphics sequence changed over time. As you'll remember, the phrase "Genesis Effect" comes from the fictional plotline of the Wrath of Khan. It's the fictional scientist Karen Marcus who uses it. Originally, the Lucasfilm team who created the computer graphics sequence (they're pictured on the right) called it the "Genesis Sequence" or the "Genesis Demo," because it was a sequence of imagery and a demonstration of their techniques.



RESEARCH CONTRIBUTIONS

Particle Systems—A Technique for Modeling a Class of Fuzzy Objects

WILLIAM T. REEVES
Lucasfilm Ltd

This paper introduces particle systems—a method for modeling fuzzy objects such as fire, clouds, and

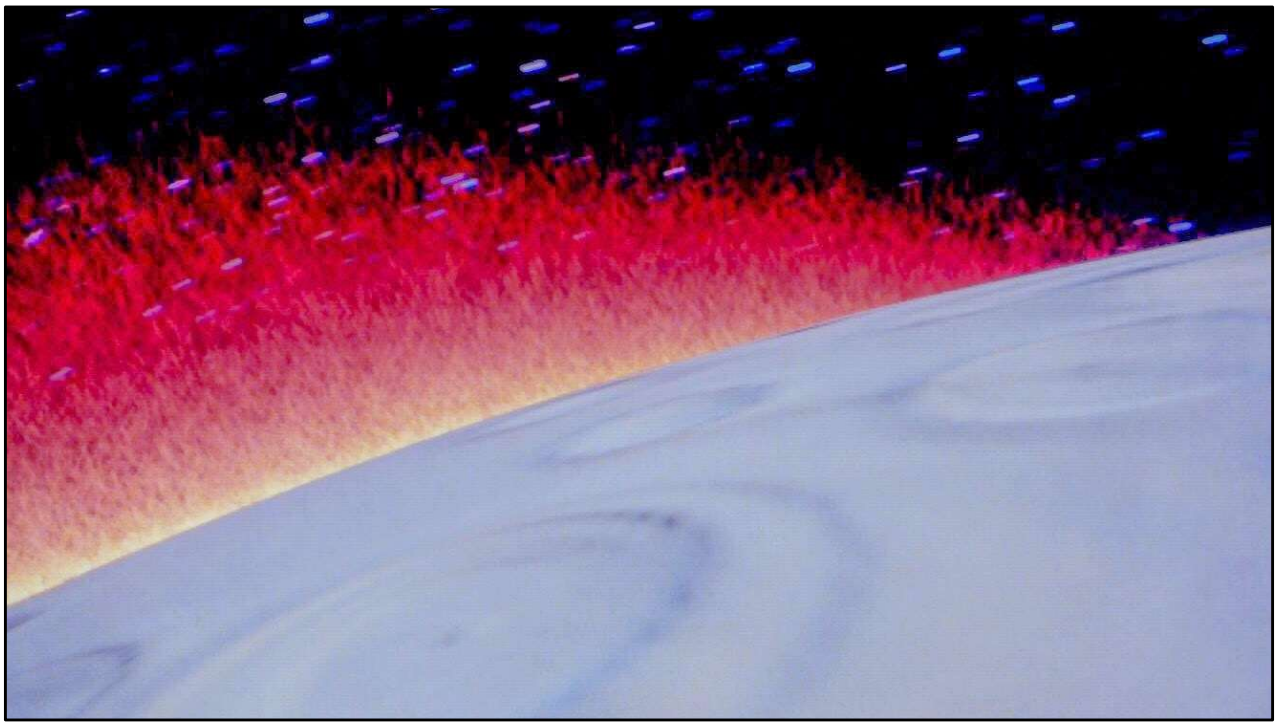
4.3 Grass

To model grass, we use an explosive type of particle system, similar to that used in the Genesis Effect. Instead of drawing particles as little streaks, the parabolic

are used to generate and control the many particles within a particle system. The application of particle systems to the wall of fire element from the Genesis Demo sequence of the film *Star Trek II: The Wrath of Khan* [10] is presented.

And yet, over time, the term “the genesis effect”—a term used originally in the storyline of the film to describe the fictional terraforming of worlds—was taken up in the descriptions of the computer graphics special effect published in academic journals. To provide the briefest of examples, we can see Reeves, one of the creators, slipping into using the term in his article about particle systems. This further blurs the distinction between the effect of an imaginary bomb on an imaginary planet, the visual simulation created by Dr. Marcus in the fictional universe of Star Trek, and the techniques used to create said effect in the offices of Lucasfilm here on Earth in the early 1980s. What’s slightly odd about this is that the Genesis sequence wasn’t a single computer graphics innovation at all: it brought together several different methods and software approaches. However, the term “the genesis effect” stuck, and you can still see it being cited that way in the computer graphics literature today.

[Click] While the clip I showed you is heavy on the sci-fi aesthetics, with its visualizations of atomic interactions and planetary bodies, at its core the Genesis effect — by which I mean both the fictional terraforming bomb and the special effect— is all about nature. You can see this in the enchanted landscape of the first Genesis test site, which is inside of a planet's interior. In this setting we encounter a veritable Eden, but more so. The waterfall doesn't merely sparkle but glows, and the oversaturated greenery belies what seems like it should be a worrisome absence of sunlight in the center of a planet.
//skipping allowed
But even more than that, we've just learned that Dr. Marcus, the creator of the genesis device, is one of Kirk's old flings. And she has secretly borne and raised Kirk's son. The boy is a reminder of what might have been if Kirk had stayed with Dr. Marcus. So as Kirk walks out into this Edenic space, which lies womblike at the center of a planet, she merely has to say "can I cook, or can't I…?" to tie her own feminine power of creation on a more domestic scale to the awesome, mythic power of the Genesis effect itself.



The word “genesis” can refer to a singular event, an origin point, or to a particular book of Old Testament. But genesis also refers to a process. And the meaning of the Genesis effect in the computer graphics research literature, as well as its on-screen special effects representation, is definitively the latter: The Genesis effect is the process of generation, not its product.

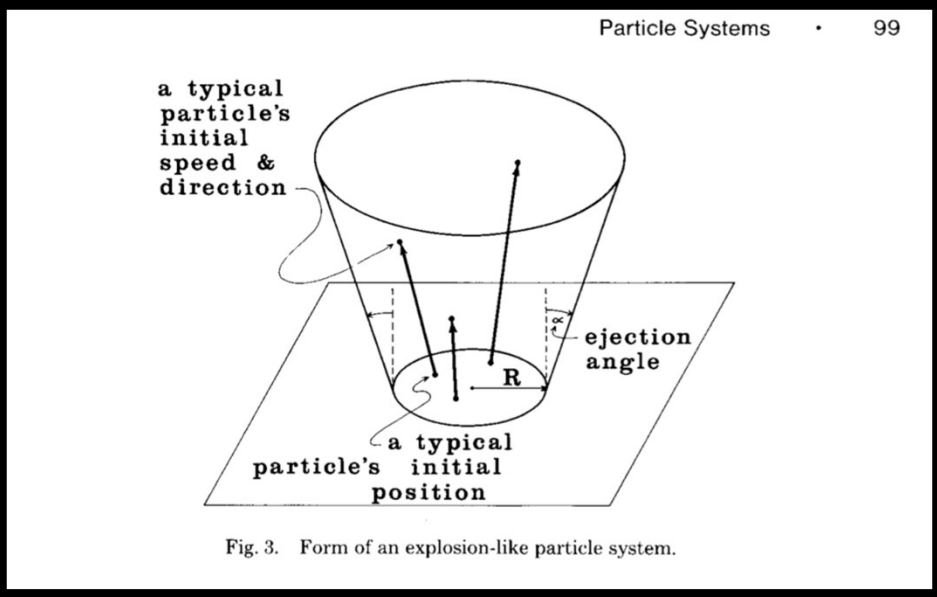
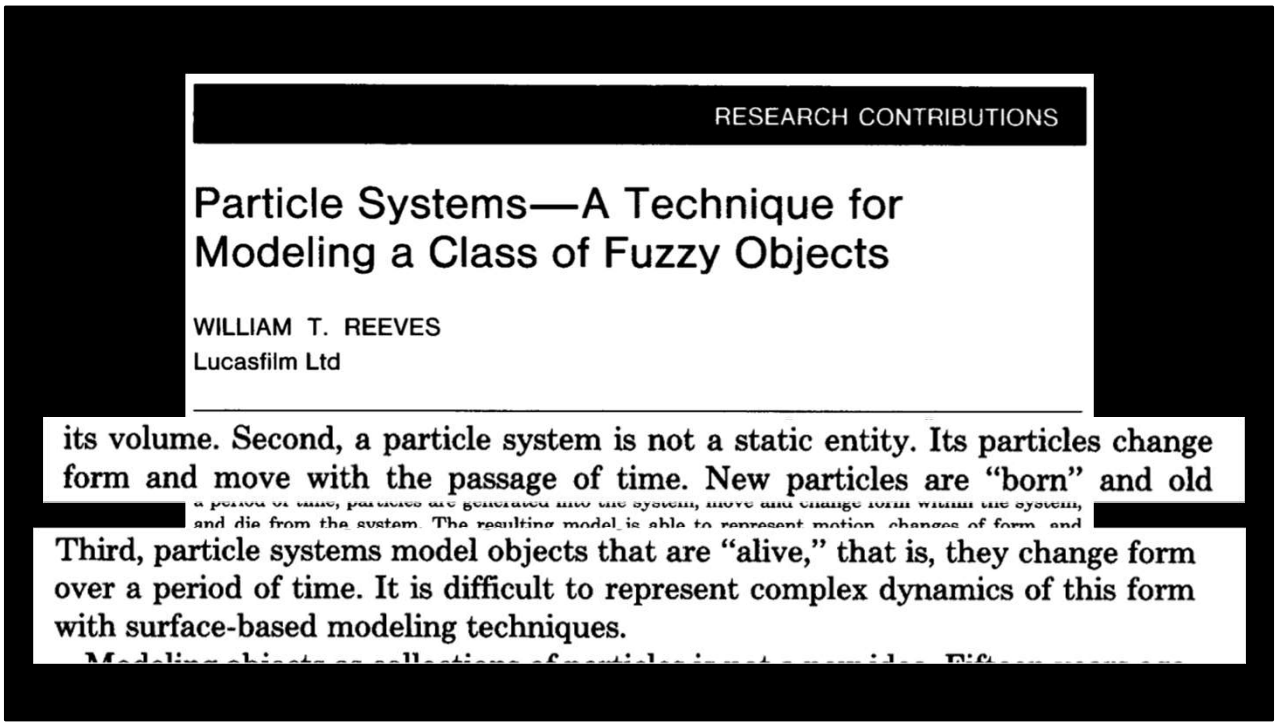


Fig. 3. Form of an explosion-like particle system.

The most important innovation from a computer graphics perspective was Reeves' particle system, with its process of spawning and destroying particles that together produced the emergent appearance of a diffuse wall of flames. [Click] It was this work that found itself being showcased in the Simulating Natural Phenomena panel at SIGGRAPH in 1983.



RESEARCH CONTRIBUTIONS

Particle Systems—A Technique for Modeling a Class of Fuzzy Objects

WILLIAM T. REEVES
Lucasfilm Ltd

its volume. Second, a particle system is not a static entity. Its particles change form and move with the passage of time. New particles are "born" and old

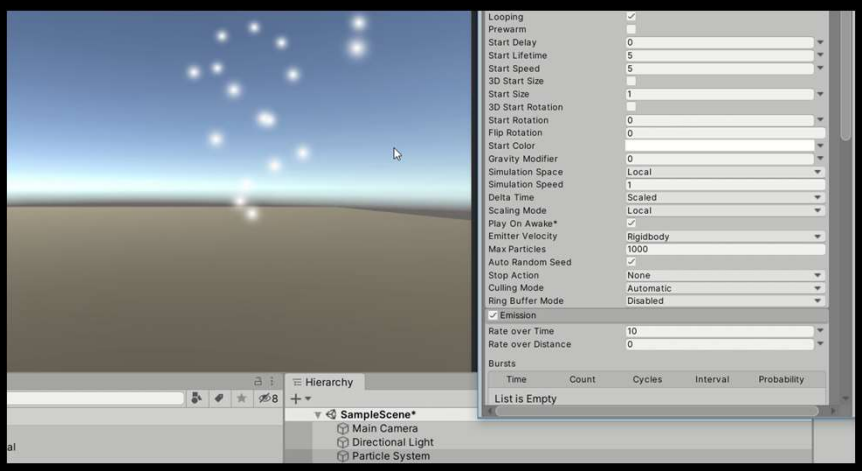
Third, particle systems model objects that are "alive," that is, they change form over a period of time. It is difficult to represent complex dynamics of this form with surface-based modeling techniques.

[Click] Explaining what he thought made particle systems useful for simulating natural phenomena, Reeves wrote, "a particle system is not a static entity. Its particles change form and move with the passage of time. New particles are 'born' and old particles 'die.'" To this set of organic metaphors he added, "particle systems model objects that are 'alive,' that is, they change form over a period of time." Life from lifelessness, indeed! Or, to echo Spock and Kirk at the end of the clip I showed you, [click]

SPOCK: “It literally is Genesis.”
KIRK: “The power of creation.”

As we’ve seen, the genesis effect is self-similar as both a fictional apparatus, a computer-generated visual effect, and a simulated natural phenomenon. This, I argue, allows Lucasfilm’s achievements in the world of computer simulation to claim some of the profound and wonderful benefits promised by Dr. Marcus in the video above—the capacity to undo and remake worlds at will.

Particle Systems as natural phenomena?



Media historian Malcolm Cook has called this kind of work on the simulation of natural phenomena part of a new paradigm in CGI in the 1980s, a "new understanding of pure mathematics as constitutive of nature." The computational universe, the reality underlying these images, began to be seen as the really real part of a natural system, a mathematical truth that explained both worldly and digital natures alike.

Part of what I find interesting about the fact that the particle systems that Reeves invented were seen as such a good example of the simulation of natural phenomena is that they are explicitly– and Reeves even admits this in his talks during the 1980s– a cheat rather than a simulation. Or rather, they are a visual simulation that need not include a physical simulation. The attached screen grab is footage I took while messing around with the particle system generator in the game engine Unity. I can turn on gravity and collision and make the particles act like physical objects, but their power and usefulness is that they don't *have* to act like physical objects. In the case of the fire that Reeves simulated for Star Trek, the particles followed simple instructions like: "Get ejected from a center at a certain angle, change color over time, move at a constant speed, and turn themselves off at a certain point determined by distance and time". That is far, far from a simulation of fire. Which is

why the same basic particle system can be used to draw grass instead of fire. The effects generated by particle systems can be really cool, and they can even be used to model some physical phenomena, but oftentimes their use is to conveniently represent physically complex things in a simple way.

So that was another example of how a story about terraforming– the creation of living worlds using a super advanced bomb that could make life from lifelessness– got taken up by technoscience to become a new kind of thing. In this case, the Genesis Effect became a kind of proof that simulated worlds in computers were working the same way that real living worlds are. As a coda to this story, I'd like to show the kind of historical effects that this same concept of natural phenomena had within the next few years. This is imagery of the planet Jupiter is from the film *2010: The Year We Made Contact*, directed by Peter Hyams and released by MGM in 1984. This film also became a landmark in computer graphics, specifically because of the swirling atmosphere of the planet. [click] In this scene, a process strikingly similar to the one enacted in The Wrath of Khan is taking place.
Jupiter is being consumed, and what is left behind is, to quote the film's script, "something wonderful," a chance at life for a new species on Europa, orbiting around a sun that was once the planet Jupiter.

[click] We even get to see Europa develop into a kind of swampy livable world, strongly evoking the Genesis Effect. In other words, we now have a genre of planetary CGI where the idea of genesis, the birth of new life on a planet, is instantiated diagetically even as a kind of genesis is also simulated on a computer (from an epistemological perspective, as the growth of new plants and the melting of glaciers are rendered).

Dallas, August 18-22 Volume 20, Number 4, 1986

Combining Physical and Visual Simulation -
Creation of the Planet Jupiter for the Film "2010"

Larry Yaeger and Craig Upson
Digital Productions

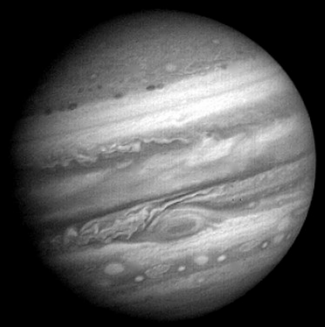
Robert Myers
Poseidon Research

1. Abstract

By integrating physical simulation, in the form of numerical fluid dynamics, with visual simulation, in the form of particle rendering, texture mapping and traditional polygonal modeling techniques, we have achieved a uniquely realistic and organic special effects sequence of a planetary atmospheric flow. This paper examines the selection, implementation, and application of these techniques, known collectively as VORTEX, to produce the moving images of the planet Jupiter in the film "2010." Details of the generation of the flow

renderer is not a final product, but serves as a texture map in a polygonal rendering system. Our texture mapping techniques are based more on the seminal works by Catmull [4] and Blinn and Newell [2] than on later efforts such as Williams [15] and Crow [5]. Our polygonal rendering model is based on a hidden surface algorithm most resembling Bouknight's [3], though any of a variety of other renderers would have served [13, 9, 12, 14]. It is the fact and methodology of combining a complex physical model with high resolution computer graphics that represents a significant development in the field of visual simulation.

In the article by computer graphics engineers Yaeger, Upson and Myers, describing their creation of Jupiter's atmosphere, they talk a lot about the idea of "Simulating Natural Phenomena," and they cite the genesis effect. In this piece of writing, it's possible to see how the idea of simulating planetary atmospheres for computer graphics got mixed up in certain ideas about nature, creating a new amalgam of science and fiction that ended up feeding back on the idea of nature itself.

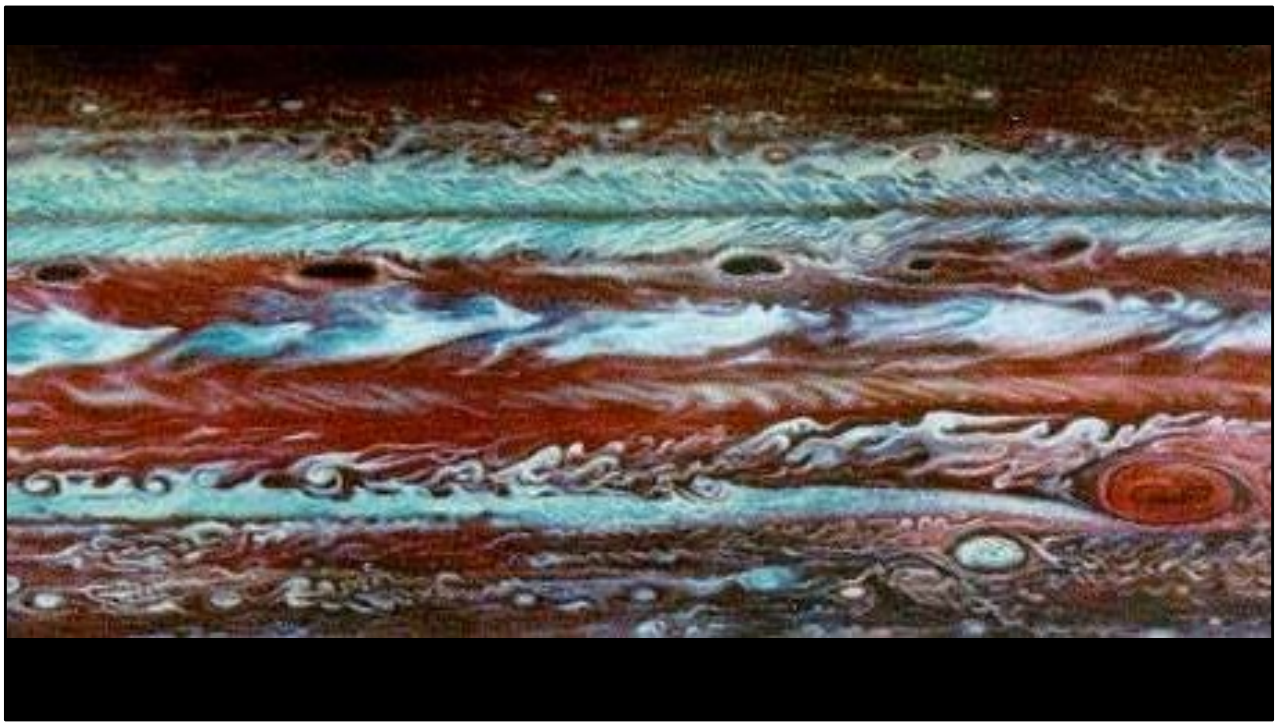


"As a result of television coverage of these fly-bys and the subsequent image analysis, the public also has certain expectations about the general behavior of the planet's atmosphere. We had selected a fluid dynamic technique that would deliver this realistic motion [but] this beginning vorticity state is quite important and must match up with the desired visual features to assure the proper advection."

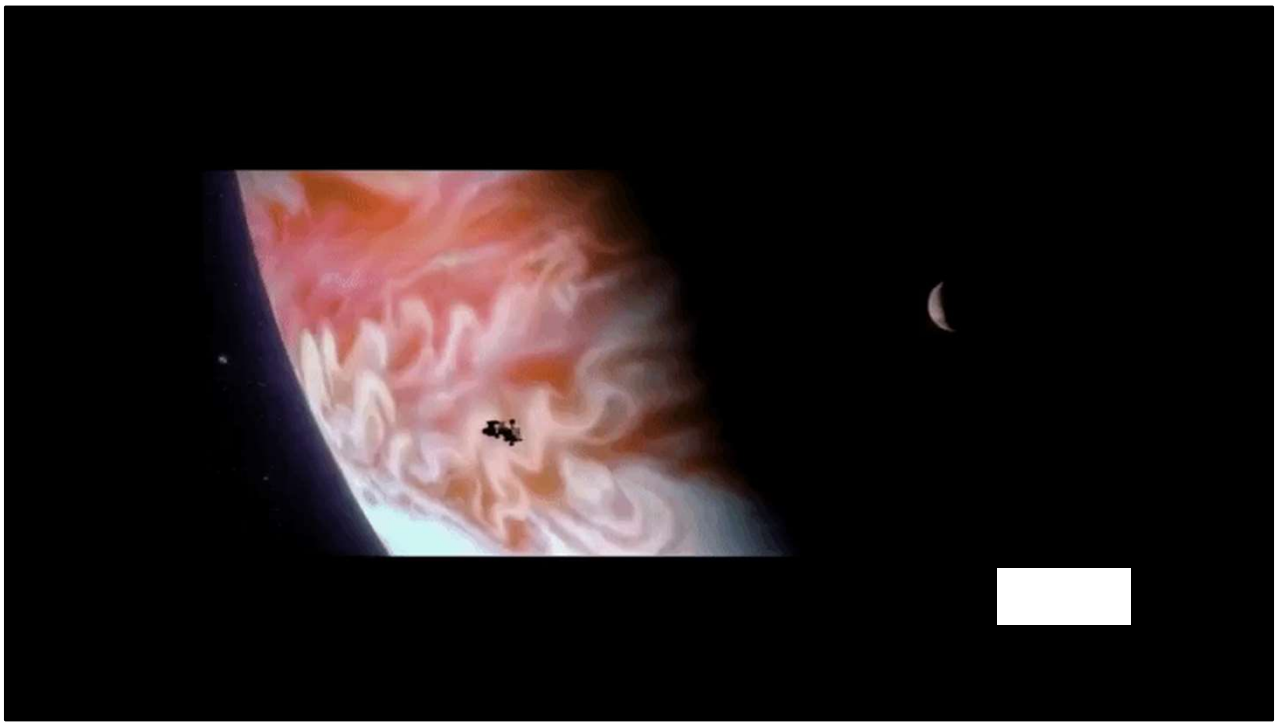
The article notes that, thanks to the prominence of the voyager probe's recent fly-bys of Jupiter on television, the public has developed an expectation of how the planet's atmosphere will move. For that reason, they initially planned to use simulation techniques to animate the actual data from NASA's flyby. However, they soon discovered that this wouldn't work.

Almost in the same breath that they claim that it was these flybys that made the public expect certain kinds of motion, they also say that that data couldn't match the public's understanding of what Jupiter is or should look like. They discovered that the data is too low-resolution, its picture too blurred and imperfect. Plus, as you might imagine, the timescales of the NASA data were off: if you watch weather in real-time from outside of a planet, it doesn't seem to move that much. But it's clear that these CGI engineers believed that the public wanted to see a swirling, seething, vortex-studded atmosphere—like a high-production-budget version of the sped-up, 30 second film clip of the flyby that took the Voyager 1 probe nearly a month to record.

So they made a giant, wallpaper sized printout of the NASA data and had a painter airbrush in all the vortices that “should” have been visible. Then this painting was scanned and loaded into a supercomputer.



Then, just as Reeves did for the Genesis effect, the production company turned the image into a particle system—as if the painting were a picture of tiny particles from space—and further manipulated it using equations for fluid dynamics and weather prediction.

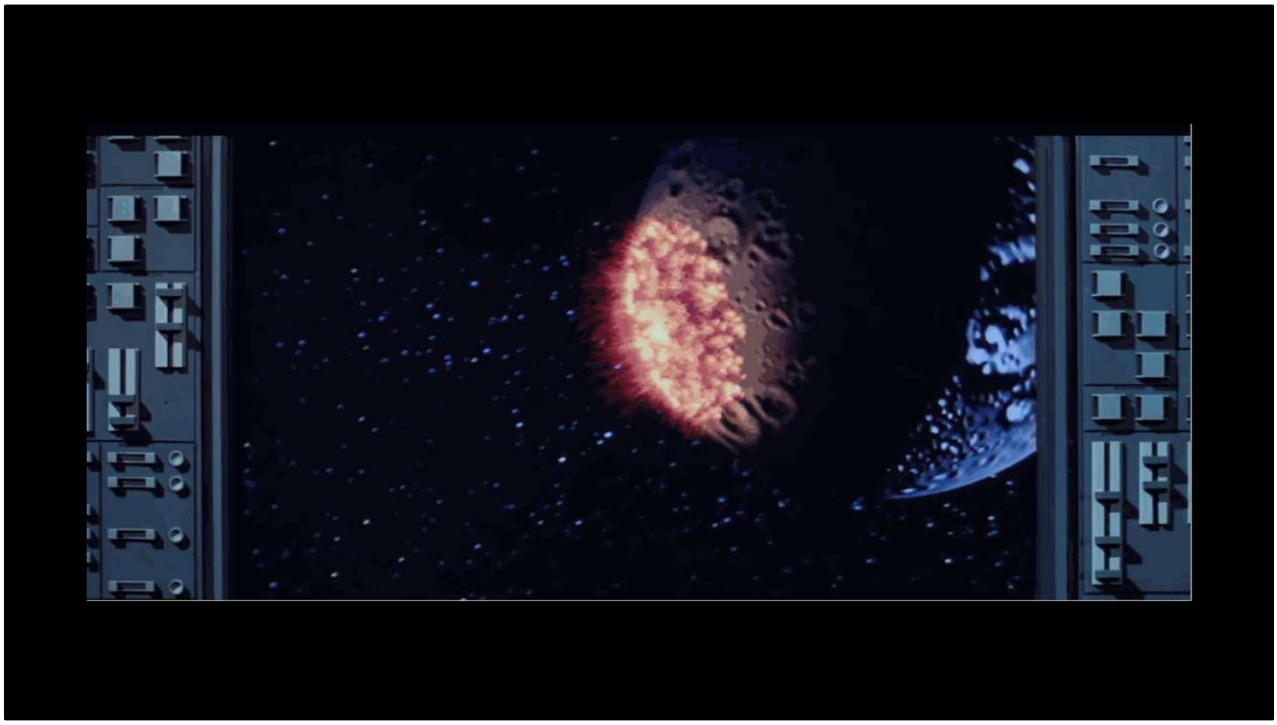


It’s worth remembering that all of this was done in the name of realism. The authors of the article celebrated Jupiter’s atmosphere in the film as a crowning achievement of the simulation of natural phenomena, and in a way, it was. But it was also (admittedly) a simulation of the public’s expectations about a natural phenomenon. This begins to develop a picture of the crucial role of computer graphics in shaping the epistemic effects of new ways of seeing. What is seen as essential in an image of a "natural" system? Once we see it we can't un-see it, and the public receives the epistemology along with the graphical representation.

physics and phenomenology of vision, we have produced strikingly realistic images of a natural, but currently unobservable phenomenon. With the advent

belying their computer graphic origins. Almost everyone has had the occasion to notice an oil slick on moving water, with its swirling rainbow hues, or a dollop of cream poured into a black cup of coffee, with the subsequent rolling filaments of light and dark. These motions are recalled--with good reason, since the physics are similar--when watching the cloud motions of the simulated Jupiter. It is not claimed that the fluid dynamics models utilized in the VORTEX system accurately portray the physics of the atmosphere of Jupiter. Yet the model is not entirely ad hoc either, and it does provide a fundamentally accurate portrayal of fluid motion. It is this natural authenticity that helps viewers to willingly suspend disbelief and to imagine themselves actually watching the great planet Jupiter swirl and churn before their eyes.

This is why I'm particularly struck by the authors' claim that their computer graphics work achieved "strikingly realistic images of a natural but currently unobservable phenomenon." Their discussion of how they mixed art and science to produce this particular version of realism is fascinating for what it does to the very notion of realism. What does it mean for an unobservable phenomenon to be rendered 'realistically'? What happens when a computer graphics simulation aims to reproduce a reality based on something the public 'already' believes in, and then that object—never before seen except in simulation—is described as a "natural phenomenon"?



What interests me here is what all these simulated planets—their production and their reception—reveal about the relationship between the epistemic, the aesthetic, and the affective. In the Computational Universe, being able to render something graphically means that you understand the computational dynamics that also underlie the real-world thing. But at the same time, this idea was perpetually bolstered by the Genesis Effects created by aesthetically spectacular images of imaginary, speculative worlds. There is a strange tension between the idea of simulating “natural” systems, and the goal of creating visions of new worlds. And yet Hollywood animators and NASA scientists were citing each other and citing climate modelers, as if the three tasks were seen as almost the same. This is a specific definition of nature that is premised upon a configuration of both stochasticity and sublimity. It is called nature, but it is really science fiction's vision of nature— to explore strange new worlds, to seek out new life and new civilizations. To boldly go where no one has gone before! And as I hope I have suggested, the construction of these worlds is all science and all science fiction, all the way down.

Thank you!

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