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Rhetorical Strategies for Audience-Specific Science Communication: Professional Writing Portfolio

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HONORS THESIS

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Introduction

In order to learn methods for communicating about science in an approachable manner to popular and more advanced audiences, I have rhetorically analyzed five pieces of popular science communication (including written pieces and oral presentations). They are:

1. *Big Bang* by Simon Singh, Harper Perennial 2005
2. "A Geometric Theory of Everything" by A. Garrett Lisi and James Owen Weatherall, *Scientific American* Dec. 2010
3. "Blood from Stone" by Mary H. Schweitzer, *Scientific American* Dec. 2010
4. "Garrett Lisi on his theory of everything," TED 2008 Conference Feb. 2008, http://www.ted.com/talks/lang/en/garrett_lisi_on_his_theory_of_everything.html
5. "Patricia Burchat sheds light on dark matter," TED 2008 Conference Feb. 2008, http://www.ted.com/talks/lang/en/patricia_burchat_leads_a_search_for_dark_energy.html
6. "NASA's Spitzer Spies Monster Galaxy Pileup" by Whitney Clavin, NASA Jet Propulsion Laboratory 6 Aug. 2007, http://www.spitzer.caltech.edu/news/260-ssc2007-13-NASA-s-Spitzer-Spies-Monster-Galaxy-Pileup

By "rhetorically analyzed," I simply mean that I judged each piece based on my perceptions of its approachability, understandability, and appeal to reader interest. To do so, I tried to put myself in the shoes of a layman. At the time of publication, I have almost completed a major in English literature with a minor in astronomy from Western Washington University. As such, I consider myself far from an expert, but rather as a beneficial liaison between experts and laymen.

I chose a variety of media forms so that I could note rhetorical moves that manifest themselves in media specific ways. I feel I was able to deduce several rhetorical moves that can be "translated" from one medium to another, and then apply some of them to my own work. While I often speak about "science writing" in this portfolio, I actually mean any type of communication about science—including TV shows, podcasts, presentations, and more.

This portfolio is a compilation of my current observations about successful science communication. Its contents do not function as a set of rigid rules but rather represent my current understanding of the successful "tools of the trade," which are open to future revision.

Included in this portfolio is a press release I authored, announcing the as-yet unpublished paper "Measuring the Ultimate Mass of Galaxy Clusters: Redshifts and Mass Profiles From the Hectospec Cluster Survey (HeCS)" by Kenneth Rines, Margaret J. Geller, and Antonaldo Diaferio. I have interviewed Dr. Kenneth Rines, a Western Washington University faculty member, multiple times to prepare this piece and ensure its utility for his research team. At the time of publication (of this portfolio), the press release is ready for publication. It will be released when the research team sees fit, likely coinciding with the paper's future publication in a scientific journal.

In this portfolio, following the finalized press release is a detailed list of the rhetorical moves I found most and least helpful in each science communication piece I analyzed—including my own press release. After this list I have included several drafts that eventually led up to the finalized press release, in order to show the creative process of writing a scientific press release. One major skill I developed throughout this project was awareness of my own writing process in this genre. While this press release took me several months to write, I spent much of that time developing helpful process skills that I will be able to repeat in much shorter time in the future.

My immediate goal for this project is to apply skills in communication with scientific understanding, as well as to understand my own creative process for writing scientific and technical communication. Briefly, I would like to note the broader implications of this project.

The longer I have studied science writing—especially that which is aimed at the general public—the more I have understood it as an empowering act. Carl Sagan argued that everyday citizens can and should be informed in the context of science and technology. In this age of technological acceleration, citizens should not let "the experts" make their decisions for them. We need access to accessible and intuitive scientific information that is appealing to read.

The best science communication, in my opinion, treats its audience with respect and understanding. It invites readers to engage with scientific information by being curious about exploring the world themselves. For the past three years, I have worked as a peer writing tutor at Western Washington University's writing center, and I am just now beginning to understand the connections between peer tutoring and science communication. As a peer tutor, I respect the authority of my tutees, and treat learning as a joint endeavor. Effective science communication should do exactly the same: educate the general public while showing it deep respect.

Specialized knowledge is attainable by everyday people who are interested in learning. It is my job as a science communicator to support access to educational scientific information for the general public. I look forward to developing my experience as a science communicator by making science accessible with my communication, education, and scientific skills.

Press Release: "Measuring the Ultimate Mass of Galaxy Clusters: Redshifts and Mass Profiles From the Hectospec Cluster Survey (HeCS)" by Kenneth Rines, Margaret J. Geller, and Antonaldo Diaferio

A team of astronomers with the Hectospec Cluster Survey (HeCS) and MMT Observatory in Arizona has estimated the ultimate sizes of 58 nearby galaxy clusters. Their findings show that the fate of these clusters is to approximately double in size before dark energy halts their growth forever, turning them into increasingly isolated "island universes."

According to our current understanding of cosmology, our universe is populated by large-scale structures (like galaxies or other types of star clusters), which grow over time. We can think of these structures as being "glued" together tightly by gravity, a force which also causes them to grow by attracting more material—such as stars, gas and dust—toward them.

Galaxy clusters are the largest astronomical structures held together by more stable or "relaxed" gravitational bonds. As such, they present unique opportunities for studying astronomical structures in detail. Galaxy clusters contain hundreds of galaxies, all of whom are attracted to each other through the force of gravity.

Like snowballs rolling down a hill, galaxy clusters grow over time by capturing more and more nearby galaxies with their gravitational pull. However, dark energy will eventually cause galaxy clusters to stop snowballing in size. Though we know very little about the mysterious force of dark energy, we have observed it in a cosmic "tug-of-war" with gravity—and galaxy clusters lie smack in the middle of the fight.

While gravity helps stabilize clusters by keeping mass tightly glued together, dark energy is pushing the universe to expand at an ever-increasing rate, making it harder for gravity to essentially "hold onto" that mass over time.

In this study, the HeCS astronomers set out to discover just how much of that material actually *will* be "held onto" by gravity in the future. Conducted by Kenneth Rines, Margaret J. Geller and Antonaldo Diaferio, the study concluded that all clusters will eventually be "holding" an amount of material that's approximately double the size of their current masses.

In comparison, most studies to date have focused on determining the mass contained within what's called the "virial radius" of galaxy clusters. Basically, this is a measurement of clusters' current sizes. But with this study, Rines and his colleagues have estimated the total mass that galaxy clusters will add to their current sizes before dark energy denies them any further growth.

Turning to the "infall regions" of 58 nearby galaxy clusters, these astronomers determined the total amount of material that will become gravitationally bound to each cluster before dark energy wins its cosmic tug-of-war. After that time, no more galaxies will be able to "fall into" that cluster's gravitational control. And once this happens, the cluster will essentially become an "island universe" as the rest of the universe zooms further away, pushed by the universe's accelerating expansion.

Of course, we have plenty of time before this actually happens. It's taken the entire age of the universe for galaxy clusters to attain their current sizes. And according to this study, each cluster will double in mass before it becomes its own isolated world.

To arrive at this figure, the astronomers selected nearby clusters from the Sloan Digital Sky Survey x-ray catalog. Gravitational forces in galaxy clusters cause intergalactic gas to travel rapidly and emit x-ray light—making them easy to detect in x-ray surveys. Once target clusters were selected from this x-ray data, the MMT telescope was used to obtain optical spectra, measuring the velocities of hundreds of galaxies in each cluster. (Spectroscopy shows how light waves are stretched and compressed by the movement of stars and galaxies.)

Next, a method called the caustic technique was used to determine which galaxies will eventually fall into a cluster's gravitational stronghold. In basic terms, we can think of this technique as an analysis of "escape velocities." Just as rockets are able to escape Earth's gravity by traveling at high speeds, fast-moving galaxies on the outskirts of clusters can avoid eventual gravitational capture because of their large velocities. By measuring these galaxy velocities at different distances from the cluster center, astronomers can determine how many galaxies are traveling slowly enough to eventually be captured by the cluster's gravity.

Detailed observations like these are uniquely possible for studying nearby galaxy clusters. The hope of the HeCS team, however, is that this model will prove applicable to the most distant clusters on our horizon. If that ends up being the case, we may hold the key to even deeper mysteries of our universe, and the role dark energy plays in its ultimate fate.

Funding for the study was provided by the Research Corporation for Science Advancement and the Smithsonian Institution.

-By Michelle Wallace

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Rhetorical Strategies

Effective Rhetorical Moves

1. **Connections to everyday experience** help the audience visualize the science in a more intuitive and tangible sense than is possible with even the clearest of logical explanations. While less appropriate in technical science communication, appeals to everyday experience are helpful to experts and non-experts alike in press releases, presentations, and magazine articles. Analogies fall under this category but are discussed separately in this list.

    - Patricia Burchat emphasizes that "By ordinary matter, I mean *you*...me, the planets, the stars; the galaxies." This helps her audience get an intuition for grouping organic matter with astronomical objects under the common category of "ordinary matter."

    - Simon Singh explains how Doppler shifts are used by police as well as astronomers: "Using Doppler shifts to measure velocities is an unfamiliar technique for most people, but it really does work. Indeed, it is so reliable that some police forces use Doppler shifts to identify speeding motorists."

    - "A Geometric Theory of Everything" begins with a clear explanation of the aesthetic and intuitive values that guide physicists to search for unified theories. These values themselves are not supported by scientific evidence, but are rather the personal judgments of real scientists. Not only is this an important scientific concept to understand, but it is easy to understand because everyone makes value judgments.

    - Mary H. Schweitzer explains a phenomenon by relating it to a common experience: "This same [phenomenon] occurs in the first bone laid down when you have a fracture—that is why you feel a lump in healing bone."

    ➔ **My Work:** In my press release, I invoke the concept of "island universes" to help the reader build an intuition for the ultimate fate of galaxy clusters. Common sense tends to connect the concept of isolation to islands themselves. In my press release, I wanted to emphasize that galaxy clusters will eventually become completely isolated.

2. **Appeals to why the science matters** are essential for creating reader interest.

    - Whitney Clavin's language is so full of excitement that it is difficult not to care about the scientific discovery she is discussing. Her first sentence reads: "Four galaxies are slamming into each other and kicking up billions of stars in one of the largest cosmic smash-ups ever observed."

- Mary H. Schweitzer implies that paleontology could ultimately help human avoid extinction as a species. She argues that "[paleontological] insights will help scientists to piece together how dinosaurs and other extinct creatures responded to major environmental changes, how they recovered from catastrophic events, and ultimately what did them in."

- Patricia Burchat envisions the future of her study by relating it to cosmology. Cosmology tends to be of great interest to a popular audience because it focuses on "the big questions" like the origin of the universe.

➔ **My Work:** A glimpse of an exciting future for cosmology just "peeks out" at the end of my press release. While maintaining focus on the specific discovery being announced, I wanted to appeal to the audience's sense of wonder by mentioning a possible implication for the discovery: that "we may hold the key to even deeper mysteries of our universe, and the role dark energy plays in its ultimate fate."

3. **Clear explanations of specific processes** empower the audience by showing that science is accessible and often "boils down" to a simple concept. Certain strategies, such as the use of analogies (which is described later in this list), can aid with this difficult task.

   - Mary H. Schweitzer explains the *mechanisms* through which scientific phenomena occur. For example, she says "One of the most compelling experiments we conducted took advantage of the immune response. When the body detects an invasion by foreign, potentially harmful substances, it produces defensive proteins called antibodies that can specifically recognize, or bind to, those substances."

   - Garrett Lisi acknowledges what his audience likely already knows and then takes it a step further by adding more information to it. This "scaffolds" the audience from what it already knows to what it wants to know, by using small "baby" steps.

   - Simon Singh even explains mathematical equations by incorporating them into the text: "Once Eratosthenes had shown that the Earth's circumference was 40,000 km, then its diameter was roughly (40,000 ÷ π) km, which is roughly 12,700 km."

   ➔ **My Work:** my press release says "Optical spectroscopy shows how light waves are stretched and compressed by the movement of stars and galaxies." This explains the concept of spectroscopy in short, basic terms.

4. **The use of analogies to describe scientific phenomena** are by nature *always* inexact. However, they can be incredibly helpful for illustrating such phenomena. Therefore, they should be used commonly to explain scientific information, but the writer must be careful not to alienate the more knowledgeable reader by an analogy that is too far off.

- In *Big Bang,* Singh says "The surface of a billiard ball is clearly not flat, but if it is repeatedly doubled in size twenty-seven times then it would be as big as the Earth. The Earth still has a curved surface, but it is much less curved than a billiard ball, and on the human scale it gives the appearance of being flat." He then uses the curvature of the Earth to help the reader visualize curved spacetime. The analogy is not entirely correct, but it is an effective way to begin understanding the concept.

- Whitney Clavin says that "one of the most elaborate known minor [galaxy] mergers is taking place in the Spiderweb galaxy -- a massive galaxy that is catching dozens of small ones in its 'web' of gravity." While gravity is not completely analogous to a sticky spider web, it can hold onto objects as tightly as a spider web clings to insects.

➔ **My Work:** My press release says that "A team of astronomers with the Hectospec Cluster Survey (HeCS) and MMT Observatory in Arizona has estimated the ultimate sizes of 58 nearby galaxy clusters," even though they actually estimated the ultimate *masses* of these galaxy clusters. Size is a more intuitive concept than mass (and weight is not an appropriate substitution), but it is an effective analogy.

5. **Representations of key concepts in multiple forms** allow readers to "wrap their minds" more fully around an idea than if it were just presented in textual form.

   - Garrett Lisi and James Owen Weatherall use simplified and colorful diagrams of many key concepts. This gives the reader an approachable and playful alternative to the text.

   - Every oral presentation I reviewed heavily utilized projected images to demonstrate key concepts in nonverbal ways.

   - Whitney Clavin's press release includes a press picture for illustrative effect.

   ➔ **My Work:** My job was to write the text for a press release, but press releases are often accompanied by captioned press pictures.

6. **Narrative form** can deeply enhance the reader's ability to maintain prolonged interest throughout a long or complex piece. Human beings are naturally drawn to stories, and information can often be related through storytelling.

   - Singh develops many key scientific figures as characters in the story of the Big Bang theory. For example, he says "Einstein, who had once been the epitome of rebellion, had become an unwitting dictator. He eventually came to appreciate the irony of his position, and once lamented: 'To punish me for the contempt for authority, Fate made me an authority myself.'" Singh even personifies inanimate objects, such as moons, at times. Making them appear like characters helps us understand their actions, because human minds naturally attribute agency to observed phenomena.

- Whitney Clavin's press release introduces "dialogue" through its use of quotations.
- Mary H. Schweitzer casts herself as the main character in a story of discovery. At the beginning of the story, she is in graduate school and has many superiors. This is her attention-grabbing story introduction: "Peering through a microscope at the thin slice of fossilized bone, I stared in disbelief at the small red spheres a colleague had just pointed out to me." By characterizing herself as an incredulous non-expert, she makes herself relatable to the reader, much like a main character of a story.

➔ **My Work:** My press release does not employ explicit narrative form, but it does take full advantage of the notion of scientific discovery as a mystery story. I conclude my written piece with the thought that "we may hold the key to even deeper mysteries of our universe, and the role dark energy plays in its ultimate fate."

7. **Appropriately minimal usage of specialized language** entails defining key terms but using them only when necessary. Informal language should be used as often as possible so that the layman can feel included in the discourse rather than overwhelmed by specialized language.

- Patricia Burchat uses the word "invisible" to describe dark matter *before* using the actual term "dark matter." This allows audience members to understand the concept before potentially being intimidated by scientific terms.
- Garrett Lisi and James Owen Weatherall introduce a term in this manner: "Over the years physicists have proposed various Grand Unified Theories, or GUTs." Not only does this clearly bring the reader from knowledge of unified theories to an understanding of the term "GUT," but the term itself has a certain ring to it. The almost careless way that Lisi and Weatherall use it implies that complicated-sounding terms are often as simple and straightforward as the word "gut."

➔ **My Work:** I use quotation marks to indicate new terminology, implying that the reader need not worry if he/she has never heard the term before. For example, I say that "the fate of these [galaxy] clusters is to approximately double in size before dark energy halts their growth forever, turning them into increasingly isolated 'island universes.'" The context of the quoted term, "island universes," also implies its definition.

8. **Inclusion of audience,** whether explicit or implied, reinforces the notion that everyday citizens can and should be part of the scientific endeavor.

- Patricia Burchat concludes her speech by inviting the audience to ask questions. Earlier in her presentation, she also asks the audience to respond to several simple leading questions, thus likely enhancing audience members' feelings of competency.

- Simon Singh tries to foresee and respond to potential audience questions. For example, he says "You might feel wary of Einstein's slightly tortuous thought experiment...Indeed, thought experiments are at the fringe of physics and are not wholly reliable...Nevertheless, Einstein's thought experiment...set him on the road to addressing the implications for a universe devoid of ether and what this meant in terms of the speed of light."

➔ **My Work:** I subtly invite the reader into the scientific discourse through phrases such as "We can think of [a particular concept in a certain way]." This "we" language is subtle enough for a press release while still being inviting to the reader.

9. **Visually breaking up the text,** such as through short paragraphs, is often helpful to keep up momentum and maintain reader interest.

    - Simon Singh includes a summary at the end of each chapter, which includes simplistic pictures and fonts that simulate handwriting. He also uses catchy section titles such as "The Gravity Battle: Newton v. Einstein" to break up the text into manageable sections, and sometimes uses bulleted lists that make the text less dense. Singh also uses frequent pictures to further break up the text into manageable portions.

    - Throughout her presentation, Patricia Burchat projects pictures and diagrams, breaking the verbal piece of her presentation into manageable chunks.

    - Garrett Lisi breaks up his presentation by focusing on quick, simple phrases, much like how some writers employ short paragraphs to break up the text. For example, Lisi says "[Quantum mechanics] can be summed up in a single sentence," focusing the reader's attention.

    - Mary H. Schweitzer's article has a large diagram on the first full page. The text in the diagram caption adds to the article rather than simply repeating information from it. Furthermore, the diagram has lots of white space, so it is not overwhelming.

    ➔ **My Work:** My press release is broken into short paragraphs of as few as two sentences. Each paragraph is intended to focus on one main idea, or one connection between multiple ideas, and thus contain no more than one complete thought.

10. **Subtle signals to specific audiences** are essential for communication that is aimed at multiple audiences. They can appear subtly, since they often simulate speech codes that signal "insiders" and "outsiders."

    - The location of information within a text can signal its intended audience. Technical information placed at the end of a write-up is usually understood as a type of "credit list" which experts may be interested in but laypeople need not worry about.

    ➔ **My Work:** Including technical terms can please experts and amateurs without confusing laypeople, if done appropriately. In my press release, I say "a method called the caustic technique was used to determine which galaxies will eventually fall into a cluster's gravitational stronghold." My wording signals to the reader that he/she need not know the term, but helps a reader with more expertise trust my understanding.

11. **Explanation of the scientific method** is sometimes necessary. Science is the endeavor to model the universe in ever more simplistic ways. Sometimes it is necessary for the audience to understand the role of models in science, as well as the scientific frame of mind.

    - Demonstrating a model of gravitational lensing using the familiar object of a wine glass helps Patricia Burchat convey the notion that scientists are searching for a *model* of physical phenomena. This use of an everyday object is illuminating *and* humorous.

    - Mary H. Schweitzer emphasizes the role of skepticism in the scientific process: "skepticism is a proper part of science, and I continue to find the work fascinating and full of promise."

    ➔ **My Work:** In an early draft of my press release, I discussed the value of skepticism in scientific pursuits, but it ended up distracting from the overall announcement of the press release. It did not seem to be necessary in this particular piece.

12. **Deliberate "signposting"** can be helpful when used in an appropriate media-specific manner.

    - In her presentation, Patricia Burchat explicitly tells her audience that "I'm going to tell you about our twenty-first century view of the universe." Throughout the speech, she continually checks in with the audience by asking "Okay?" In presentations, this type of direct signposting can help a presenter sound both clear and approachable.

    - Throughout his long text, Singh must frequently draw the reader's attention back to the main ideas. For example, once he brings up Einstein's cosmological constant, he relates it a different concept discussed much earlier in the book—showing that they are both examples of a main concept in the book. Singh also draws connections between ideas by repeating key words and phrases. This is an example of more subtle signposting that can be used more appropriately in short written pieces.

➔ **My Work:** My press release links main ideas through repeated key words. For example, the first paragraph introduces a key idea that is referenced several paragraphs later through the repetition of a key word.

13. **Humor** enhances a sense of belonging, and can thus increase the layman's sense of competency in his/her ability to understand a concept.

- Garrett Lisi, a surfer and physicist, opens up his oral presentation by exclaiming "Whoa, dude, check out those killer equations!" and pointing to complex equations on display through a projector.

- Patricia Burchat recommends using a wine glass to model gravitational lensing. Showing a picture of a wine glass, she says "This is your instrument." Burchat makes the audience laugh by calling a wine glass a scientific instrument, but more importantly she uses this joke to show the audience that science is a process that everyone can take part in—because she shows that she is a normal person.

- A blown-up quote on the side of Mary H. Schweitzer's article humorously captures the reader's interest in dinosaur bones: "'Oh, my gosh, it's a girl—and it's pregnant!' I exclaimed to my assistant. She looked at me like I had lost my mind."

➔ **My Work:** I decided to appeal to wonder rather than humor in my press release. With such a short piece, appealing to both may simply end up as distracting.

Ineffective Rhetorical Moves

1. **Failure to explain the context and/or the scientific process** can be the downfall of a write-up or presentation, especially when the science at hand is counterintuitive.

    - Garret Lisi presents and writes about geometry as a model for particle physics. However, he does not explain what he means by "geometrical." Since everyone intuitively experiences geometry in three-dimensional objects, the concept of geometry as a *model* instead of an "actual *thing*" is deeply counter-intuitive and requires ample explanation.

2. **Using specialized terminology** when unnecessary, and/or without either a definition or a signal to the audience that understanding is not essential, is discouraging to the audience. It reinforces the notion that science is inaccessible and scientists are unquestionable experts.

    - Mary H. Schweitzer's article uses phrases like "porous sands allow the corrosive fluids that form during decomposition to drain away," which use specialized terms when more intuitive everyday language could be just as effective.

    - Patricia Burchat uses terms like "potential," "function," and "electromagnetic spectrum" without acknowledging that they're specialized terms which the audience might not understand.

    - Garrett Lisi and James Owen Weatherall use the term "accelerators" without even a brief re-cap for moderately knowledgeable readers. This occurs in the second paragraph of their article, and sets the tone of the piece.

3. **Lack of explanation of the mechanism at work** makes a piece difficult to understand. Audiences tend to want to know not only the phenomenon being observed by scientists, but the theories scientists have about what mechanism causes the phenomenon to occur.

    - Garrett Lisi and James Owen Weatherall say that "a separate geometric object governs each force" in the currently accepted theory, but do not explain what mechanism would allow a geometric object to govern a force of nature.

4. **Presentation of a complex concept without breaking it into smaller "baby" steps** can create confusion for a reader who is perfectly capable of understanding the subject.

    - Whitney Clavin says that NASA's Chandra X-Ray Observatory was used to "weigh the mass of [a] giant cluster of galaxies." However, she does not explain how such a measurement is possible through x-ray observation. This small baby step is needed to build a complete understanding.

- In their article, A. Garrett Lisi and James Owen Weatherall assert that the currently accepted theory is "somewhat of a patchwork" because "a separate geometric object governs each force" without explaining why it is a problem for separate geometric objects to drive each force of nature. Because they don't stop to explain this before they present their next piece of information, the reader may be too distracted to follow the authors to the next step. Creating smaller baby steps would keep the reader with them along the way.

5. **Too many details or repetition** can lengthen science writing or a presentation. This, in turn, can make the information less accessible to the reader by representing a greater time commitment.

    - Simon Singh includes several tangents and stories that are not related closely enough to the overall story of the Big Bang theory. For example, he tells a story about Edwin Hubble's sister that isn't relevant to the book's main point. *Big Bang* also frequently uses captions that repeat lots of information from the main text. This breaks up the flow of the text in a way that *adds* a burden to the reader rather than taking it away.

6. **Inside jokes** can alienate audience members when they are not invited into the "inside."

    - Garrett Lisi makes a joke about another scientist in his presentation, but some audience members are undoubtedly unfamiliar with the scientist.

Writing Process Strategies: Introduction

After studying some excellent pieces of science writing, I thought that writing a press release about a scientific discovery would be a fairly straightforward process. After recognizing the effective techniques of other science communicators, though, I realized that there was more involved in science writing than just applying those strategies myself. For example, I understood the *concept* of an effective analogy, but actually coming *up* with an appropriate analogy for a scientific concept is more of a creative process than a logical one. If science communication is about helping people build intuitions about complex topics, then effective science writing must take a lot of creative envisioning to relate science through intuitive language.

With this project, I learned that science writing is a creative process—at least for myself. Even though science writing must communicate important technical concepts, I can be creative in the way I come up with effective wording to do so. This project took me a long time to complete, partially because I was trying to "just sit down and write it." But eventually, by going through multiple drafts and re-envisioning concepts in different ways, I was able to create my most effective and joyful—and hence more readable—writing. This is an essentially creative process.

Now that I have taken the time to understand my own writing process, I will be able to apply it under stricter deadlines in the future. I look forward to developing my writing process to become even more effective in the future. I want to keep developing my own unique and creative voice as an effective science writer, so that my readers will be interested in learning about science.

On the following pages, I present a sample of my preliminary drafts (from earliest to latest), leading up to my final product. In many places, I have preserved handwritten edits in order to demonstrate the creative aspects of the writing and revising processes.

Preliminary Brainstorming Excerpts

Although Einstein revolutionized our view of the cosmos, he believed in a steady state universe—one which is neither expanding nor contracting. So when his relativistic calculations implied that the universe was actually *contracting* due to gravity, he plugged a number into his equations. This number, called the cosmological constant, did not correlate to anything in the real world—it was simply a number that allowed his equations to account for a steady state universe.

highlights = use this material

Over time, the cosmological constant began to seem clearly *wrong.* Our technology, by this time, had advanced far enough that we could observe the aftermath of the Big Bang. Basically, our telescopes became powerful enough that we could finally detect the light emitted at the Big Bang that still permeates space today. Common analogies to this light (a.k.a. the cosmic microwave background radiation) describe it as the glowing embers of the Big Bang that formed the universe.

(although the constant ~~is dif~~ has a different value now, the concept is essentially the same.)

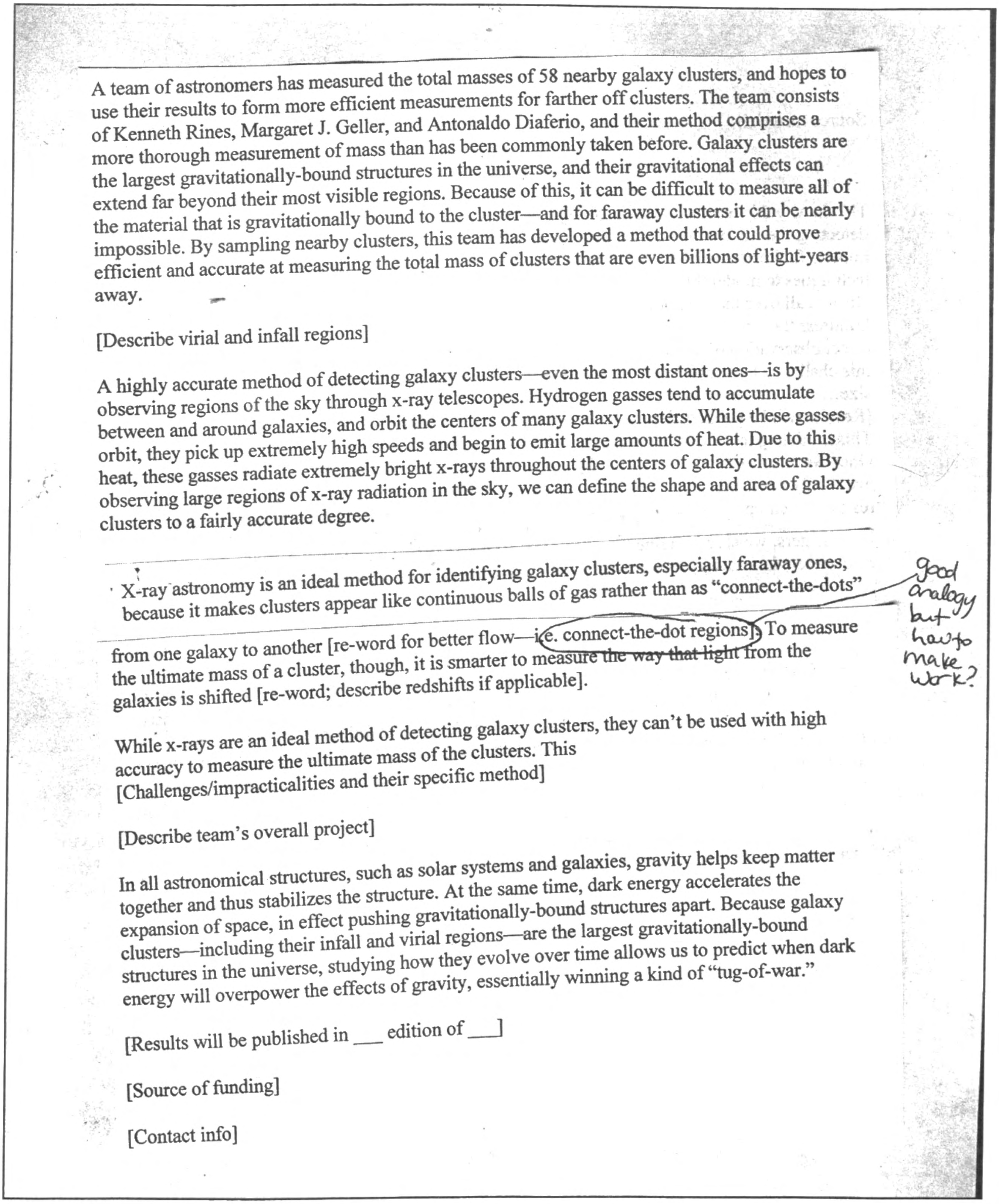
Today, however, the cosmological constant has come full circle, and now helps account for the presence of *dark energy* in the universe. In a nutshell, the cosmological constant stands for a force that pushes the universe apart, counteracting the tendency for gravity to pull the universe in on itself. While

wrong

the discovery of the microwave background radiation essentially proved that the universe is expanding—counter to the purpose of Einstein's cosmological constant which kept the universe at a steady state—some form of the cosmological constant now fully accounts for a recent astounding cosmological discovery: that the universe is expanding at an *increasing rate.* The mysterious force that is accelerating the expansion of the universe is called *dark energy,* and it is one of the biggest blanks that modern cosmology seeks to fill in.

While it takes the work of one genius to reform an entire worldview, the job of filling in the details of a new paradigm is no less noble. Countless astronomers, physicists and cosmologists today work diligently to discover the details of an expanding universe driven by a cosmological constant—dark energy.

In essence, dark energy works against gravity by pushing matter apart rather than drawing it together. These opposing forces have been likened to a cosmic tug-of-war, and one of the most scintillating questions in modern cosmology is *when does dark energy win?* The current state of the universe supports large-scale structures bound by gravity. Without such stable structures, we would not have a home on Earth—or anywhere else for that matter. But it seems only logical that, if the universe is expanding at an ever-increasing rate, eventually gravity will not be able to hold structures together anymore, and dark energy will "win the tug-of-war," so to say. To learn more about this ultimate fate, then, we can learn a lot from the largest gravitationally-bound structures in the cosmos: galaxy clusters. By studying how the structure of galaxy clusters evolves over time, it turns out, we can learn a lot about the opposing forces of gravity and dark energy that act upon structures in our universe.



A team of astronomers has measured the total masses of 58 nearby galaxy clusters, and hopes to use their results to form more efficient measurements for farther off clusters. The team consists of Kenneth Rines, Margaret J. Geller, and Antonaldo Diaferio, and their method comprises a more thorough measurement of mass than has been commonly taken before. Galaxy clusters are the largest gravitationally-bound structures in the universe, and their gravitational effects can extend far beyond their most visible regions. Because of this, it can be difficult to measure all of the material that is gravitationally bound to the cluster—and for faraway clusters it can be nearly impossible. By sampling nearby clusters, this team has developed a method that could prove efficient and accurate at measuring the total mass of clusters that are even billions of light-years away.

[Describe virial and infall regions]

A highly accurate method of detecting galaxy clusters—even the most distant ones—is by observing regions of the sky through x-ray telescopes. Hydrogen gasses tend to accumulate between and around galaxies, and orbit the centers of many galaxy clusters. While these gasses orbit, they pick up extremely high speeds and begin to emit large amounts of heat. Due to this heat, these gasses radiate extremely bright x-rays throughout the centers of galaxy clusters. By observing large regions of x-ray radiation in the sky, we can define the shape and area of galaxy clusters to a fairly accurate degree.

X-ray astronomy is an ideal method for identifying galaxy clusters, especially faraway ones, because it makes clusters appear like continuous balls of gas rather than as "connect-the-dots" from one galaxy to another [re-word for better flow—i.e. connect-the-dot regions]. To measure the ultimate mass of a cluster, though, it is smarter to measure ~~the way that light~~ from the galaxies is shifted [re-word; describe redshifts if applicable].

good analogy but have to make work?

While x-rays are an ideal method of detecting galaxy clusters, they can't be used with high accuracy to measure the ultimate mass of the clusters. This
[Challenges/impracticalities and their specific method]

[Describe team's overall project]

In all astronomical structures, such as solar systems and galaxies, gravity helps keep matter together and thus stabilizes the structure. At the same time, dark energy accelerates the expansion of space, in effect pushing gravitationally-bound structures apart. Because galaxy clusters—including their infall and virial regions—are the largest gravitationally-bound structures in the universe, studying how they evolve over time allows us to predict when dark energy will overpower the effects of gravity, essentially winning a kind of "tug-of-war."

[Results will be published in ___ edition of ___]

[Source of funding]

[Contact info]

First Draft

A team of astronomers with the Hectospec Cluster Survey (HeCS) has estimated the ultimate masses of 58 nearby galaxy clusters—that is to say, the total mass that each cluster will accrue before eventually being ripped apart by the mysterious force of dark energy.

To date, most studies have focused only on determining the mass contained within what is called the "virial radius" of galaxy clusters. Mass within this radius is relatively close to the cluster center and is tightly "glued" to the cluster by gravity. Measuring the mass inside this radius gives us the current mass of the cluster. But like snowballs rolling down a hill, galaxy clusters grow over time, consuming more and more nearby galaxies as they grow older. So what will the clusters look like in the far-off future—and when will they stop snowballing in size?

The HeCS team has turned to the "infall regions" of nearby galaxy clusters to estimate the total mass these clusters will eventually attain. For each cluster, they have determined that this ultimate mass will be right around two times its current mass, and this number agrees well with computer simulations. With such a clear-cut pattern, might we have on our hands a model of what *all* galaxy clusters will eventually evolve to?

As in all science, only time can tell, but it's quite possible that we will be able to apply this model to even the most distant galaxy clusters on our horizon. What's especially exciting about this is the prospect of studying extremely young clusters. When we observe clusters that are billions of light years away, we are actually seeing them as they appeared billions of years ago, when the light that is now reaching our eyes first left the cluster. Applying this model to faraway clusters, then, could allow us to more deeply study infant galaxy clusters of the distant past—which could tell us more about the forces that cause them to "snowball" as they grow up.

According to Dr. Kenneth Rines of Western Washington University, lead author of the HeCS study, gravity helps stabilize cosmic structures like galaxy clusters by keeping mass tightly "glued" together. However, the recent discovery of "dark energy" shows that these astronomical structures will eventually be blown apart because space is expanding at an ever-increasing rate. By determining how much mass a galaxy cluster can consume before dark energy overcomes the force of gravity, we can get closer to understanding how dark energy will affect the ultimate fate of our universe.

HeCS's current study has been selected for publication in ______. With its focus on modeling the ultimate mass of galaxy clusters based solely on their current masses, its aim is to develop a practical method for observing the effects of dark energy. It is nearly impossible to observe the infall regions of faraway galaxy clusters, since they can extend well beyond the most visible regions of these already-faint clusters. So by proposing a model based on closer, more well-defined clusters, this study offers a practical tool for probing the depths of the faintest and most infantile clusters in the sky.

Taking measurements on nearby clusters is, however, a challenge in and of itself. One highly accurate method for detecting galaxy clusters is by observing regions of the sky through x-ray telescopes. Hydrogen gasses "ball up" between and around galaxies, and orbit the centers of many galaxy clusters at extremely high speeds. These orbiting gasses heat up—kind of like friction building on a fast-moving car tire—and begin to emit bright x-ray light all throughout cluster centers. So by using x-ray astronomy, we no longer need to play "connect the dot" between galaxies to define clusters—but can detect a cluster as a ball of x-ray light. So, drawing upon existing x-ray measurements from the Sloan Digital Sky Survey (SDSS), HeCS selected the 58 galaxy clusters that they used in this study.

However, x-rays quickly dim out as you move away from the center of the galaxy cluster, and aren't even bright enough on the outskirts of clusters to determine the *current* masses of these clusters—let alone the ultimate masses they will attain. So once the HeCS team determined their target clusters from SDSS, they turned to measurements of "redshifted" light to measure the masses of these clusters.

Redshifts are, in effect, tangible manifestations of the expansion of the universe. Because space itself is expanding, most large scale cosmological structures such as galaxies can be seen to move away from an observer standing at *any* point in space. And when a star or galaxy moves away from us, we can see that the light it emits gets distorted so as to appear slightly "redder" (a.k.a. to have a longer wavelength). And the "redder" a galaxy is, it turns out, the further away it is from us.

The model that this team has developed is a huge advancement in their overall project of modeling galaxy cluster evolution. Eventually, they hope to take data from further clusters to form a "story" of cluster evolution by comparing them to closer clusters. Because light travels at a fixed speed, light from faraway clusters takes so much time to reach us that we are in a sense observing them as they appeared billions of years ago, when they were much younger. If that "story" matches up with the model they have just developed, we will be well on our way to building a stronger and more complete understanding of galaxy cluster evolution, and the future of our universe.

Funding for the project has been provided by ________.

Contact:

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Second Draft

HP1

A team of astronomers with the Hectospec Cluster Survey (HeCS) has estimated the ultimate masses of 58 nearby galaxy clusters—that is to say, the total mass that each cluster will accrue before eventually being ripped apart by the mysterious force of dark energy.

HP2

from the cluster center

To date, most studies have focused only on determining the mass contained within ~~what is called~~ the "virial radius" of galaxy clusters. Mass within this distance is ~~relatively close to the cluster center and is~~ tightly "glued" to the cluster by gravity. ~~Measuring this "virial mass" gives us the current mass of the cluster.~~ But like snowballs rolling down a hill, galaxy clusters grow over time, capturing ~~consuming~~ more and more nearby galaxies ~~as they grow older~~. So what will the clusters look like in the far-off future—and ~~when will they~~ stop snowballing in size?

so this mass effectively tells us the clusters current size

with their gravitational pull

why will they eventually

~~what will cause them to eventually~~

Why: dark energy

HP4

The HeCS team has turned to the "infall regions" of nearby galaxy clusters to estimate the total mass these clusters will eventually attain. For each cluster, they have determined that this ultimate mass will be right around two times its ~~current~~ mass, ~~and this number~~ agrees well with computer simulations. ~~So with a pattern like this, might we have on our hands a model of what *all* galaxy clusters will eventually evolve to?~~ ?

before

dark energy wins out on tug-of-war

With a bit of healthy scientific skepticism, the HeCS team feels optimistic that their estimate ~~could~~ lead to a model of how all galaxy clusters evolve over time. Such a model would be invaluable to the far-reaching implications of studying galaxy clusters. For instance, what if we could accurately model the evolution of extremely distant—and incredibly dim—galaxy clusters? Could that tell us anything about the universe's ultimate fate?

Their hope is…

Read press releases

space.com

compare to articles

"Live Science"

According to Dr. Kenneth Rines of Western Washington University, lead author of the HeCS study, when we observe clusters that are billions of light years away, we are actually seeing them as they appeared billions of years ago (when the light that is now reaching our eyes first left the cluster). Applying this model to faraway clusters, then, could allow us to more deeply study infant galaxy clusters of the distant past—which could tell us more about the forces that cause them to "snowball" as they grow up.

As it turns out, the most mysterious force at work in the evolution of galaxy clusters is "dark energy." The other force involved—gravity—~~is equally mind-boggling~~, but we *do* know that it helps stabilize cosmic structures (like galaxy clusters) by keeping mass tightly "glued" together. However, the recent discovery of dark energy shows that these astronomical structures will eventually be blown apart because space is expanding at an ever-increasing rate. By determining how much mass a galaxy cluster can consume before this mysterious force overtakes gravity's "pull," we can get closer to understanding the ultimate fate of our universe.

capture

astro physics pre-prints

making it harder for gravity to hold on

Building models, like HeCS is attempting to do, is necessary if we are ever to delve into an understanding of this ultimate fate. It is nearly impossible to observe the infall regions of

too many questions

give a "glimpse" at the end of the "so what"?

faraway galaxy clusters, since they can extend well beyond the most visible regions of these already-faint clusters. Only by modeling them can we hope to probe the depths of the most ancient artifacts in our sky—and come to understand their cosmological implications.

Taking measurements of even young, nearby clusters is, however, a challenge in and of itself. One highly accurate method for detecting galaxy clusters is by observing regions of the sky through x-ray telescopes. In galaxy clusters, hydrogen gasses "ball up" between and around galaxies, orbiting the cluster at extremely high speeds. These orbiting gasses heat up (kind of like friction building on a fast-moving car tire) and begin to emit bright x-ray light. So by using x-ray astronomy, we no longer need to play "connect the dot" between galaxies to define clusters—because they appear clearly as balls of x-ray light in the night sky.

However, x-rays quickly dim out as you move away from the center of the galaxy cluster, and aren't even bright enough on the outskirts of clusters to determine the *current* masses of these clusters—let alone the ultimate masses they will attain. So HeCS used the Sloan Digital Sky Survey (SDSS), a catalog of x-ray astronomy, to determine the locations of the 58 nearby galaxy clusters they would point their telescopes at for this study. Once they had those telescopes fixed at those locations (so to speak), they turned to measurements of "redshifts" in light to measure the actual masses of these clusters.

Redshifts are, in effect, tangible manifestations of the expansion of the universe. Because space itself is expanding, most large cosmological structures like galaxies can be seen to move away from an observer standing at *any* point in space. And when a star or galaxy moves away from us, we can see that the light it emits gets distorted so as to appear slightly "redder" (or in other words, to have a longer wavelength). It also turns out that the "redder" a galaxy is, the further away it is from us—and so the measurement of a "redshift" shows us how far a galaxy is from us.

Because galaxies that belong to the same cluster tend to be located at roughly the same distance from our own galaxy, HeCS was able to use this method to estimate how many galaxies belong to nearby, x-ray identified clusters *and* their infall regions. Multiplying this number by an average mass of galaxies gives us an approximation of the ultimate mass that a cluster will attain before falling apart. And, as HeCS determined, this mass seems to be right around twice the current mass of all galaxy clusters.

Only time will tell how HeCS's model will come to be applied throughout the cosmos. One can only imagine the questions this endeavor will answer about the fate of our universe—and the new questions it will bring up that we never dreamed of before.

-Michelle Wallace (Western Washington University)

To read more about this study, see the ___ issue of ____, where HeCS's results will be published for peer review.

Contact:

Because this data is much easier to get for close clusters -

velocities → masses
(orbital velocities → escape velocities → masses)
Same way that velocities of stars reveal presence of dark matter

Third Draft

A team of astronomers with the Hectospec Cluster Survey (HeCS) has estimated the ultimate masses of 58 nearby galaxy clusters—that is to say, the total mass that each cluster will accrue before eventua~~ll~~y being ripped apart by the mysterious force of dark energy.

To date, most studies have focused only on determining the mass contained within the "virial radius" of galaxy clusters. Mass within this distance is tightly "glued" to the cluster by gravity, so this mass effectively tells us the cluster's *current* size. But like snowballs rolling down a hill, galaxy clusters grow over time, capturing more and more nearby galaxies with their gravitational pull. So what will the clusters look like in the far-off future—and why will they eventually stop snowballing in size?

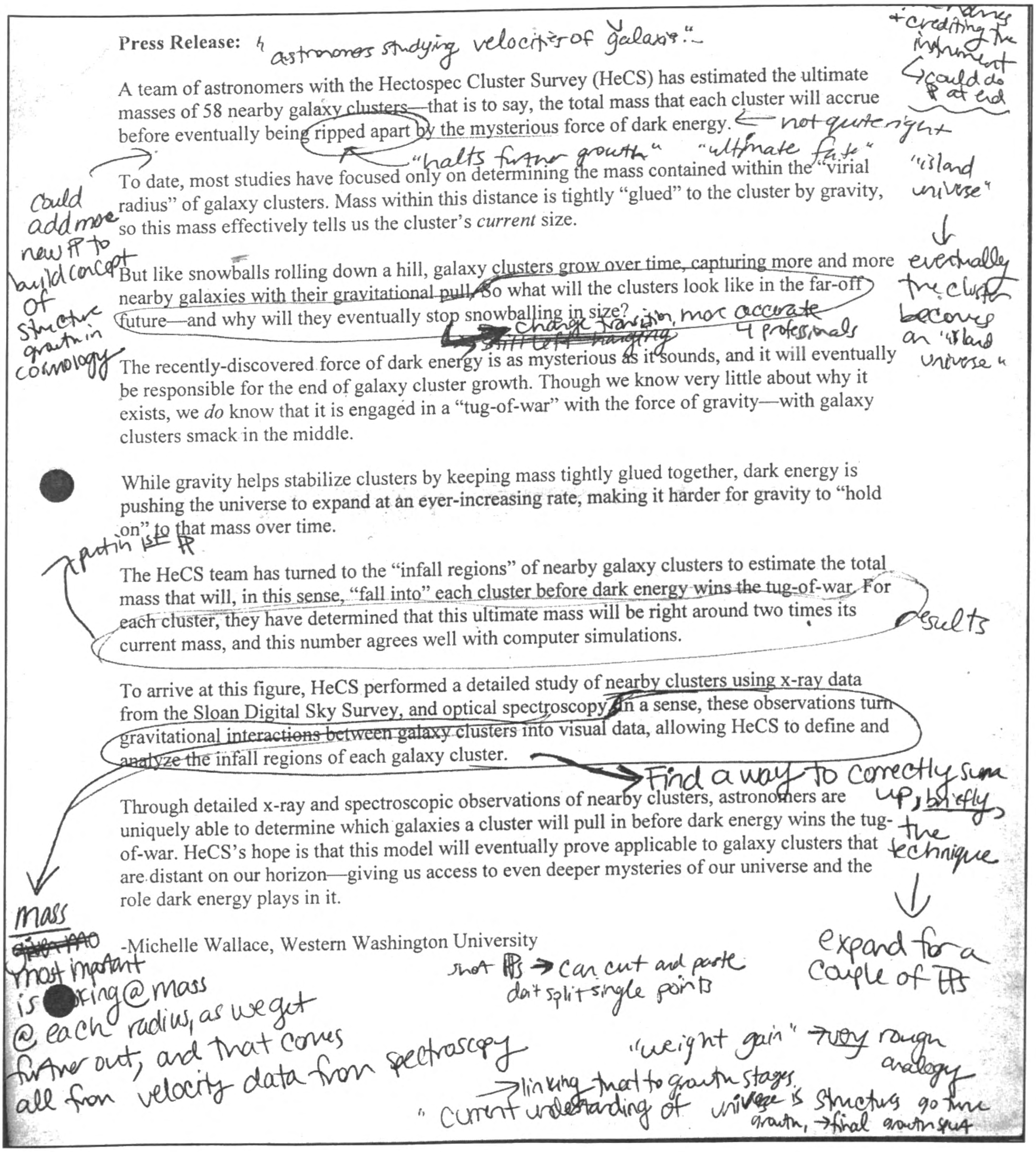
The recently-discovered force of dark energy is as mysterious as it sounds, and it will eventually be responsible for the end of galaxy cluster growth. Though we know very little about why it exists, we *do* know that it is engaged in a "tug-of-war" with the force of gravity—with galaxy clusters smack in the middle. While gravity helps stabilize clusters by keeping mass tightly "glued" together, dark energy is pushing the universe to expand at an ever-increasing rate, making it harder for gravity to "hold on" to that mass over time.

The HeCS team has turned to the "infall regions" of nearby galaxy clusters to estimate the total mass that will "fall into" each cluster before dark energy wins the tug-of-war. For each cluster, they have determined that this ultimate mass will be right around two times its current mass, and this number agrees well with computer simulations.

in this sense

To arrive at this figure, HeCS performed a detailed study of nearby clusters using x-ray data from the Sloan Digital Sky Survey, and optical spectroscopy. Collectively, these observations turn galaxy proximities and gravitational ~~"pulls"~~ interactions between them into visual data, allowing HeCS to define and analyze the infall regions of each galaxy cluster. ~~Only~~ through ~~such~~ detailed ~~observations~~ x-ray and spectroscopic observations of nearby clusters ~~are we~~ astronomers ~~HeCS is~~ are uniquely able to determine ~~the extent of each cluster's gravitational influences, and~~ which galaxies a cluster will pull in before dark energy ~~takes over~~ wins the tug-of-war. HeCS's ~~dream~~ hope is that this model, ~~borne of such detailed observations of nearby galaxy clusters,~~ may prove applicable to futher and more distant clusters—giving us access to even deeper mysteries of our universe and the role dark energy plays in it.

Fourth Draft



Press Release: "astronomers studying velocities of galaxies"

+ crediting the instrument ← could do ¶ at end

A team of astronomers with the Hectospec Cluster Survey (HeCS) has estimated the ultimate masses of 58 nearby galaxy clusters—that is to say, the total mass that each cluster will accrue before eventually being ripped apart by the mysterious force of dark energy. ← not quite right

"halts further growth" "ultimate fate"

"island universe" ↓ eventually the cluster becomes an "island universe"

To date, most studies have focused only on determining the mass contained within the "virial radius" of galaxy clusters. Mass within this distance is tightly "glued" to the cluster by gravity, so this mass effectively tells us the cluster's *current* size.

Could add more new ¶ to build concept of structure growth in cosmology

But like snowballs rolling down a hill, galaxy clusters grow over time, capturing more and more nearby galaxies with their gravitational pull. So what will the clusters look like in the far-off future—and why will they eventually stop snowballing in size?

~~still left hanging~~ change transition, more accurate 4 professionals

The recently-discovered force of dark energy is as mysterious as it sounds, and it will eventually be responsible for the end of galaxy cluster growth. Though we know very little about why it exists, we *do* know that it is engaged in a "tug-of-war" with the force of gravity—with galaxy clusters smack in the middle.

While gravity helps stabilize clusters by keeping mass tightly glued together, dark energy is pushing the universe to expand at an ever-increasing rate, making it harder for gravity to "hold on" to that mass over time.

put in 1st ¶

The HeCS team has turned to the "infall regions" of nearby galaxy clusters to estimate the total mass that will, in this sense, "fall into" each cluster before dark energy wins the tug-of-war. For each cluster, they have determined that this ultimate mass will be right around two times its current mass, and this number agrees well with computer simulations. results

To arrive at this figure, HeCS performed a detailed study of nearby clusters using x-ray data from the Sloan Digital Sky Survey, and optical spectroscopy. In a sense, these observations turn gravitational ~~interactions between galaxy~~ clusters into visual data, allowing HeCS to define and analyze the infall regions of each galaxy cluster.

Find a way to correctly sum up, briefly, the technique ↓ expand for a couple of ¶s

Through detailed x-ray and spectroscopic observations of nearby clusters, astronomers are uniquely able to determine which galaxies a cluster will pull in before dark energy wins the tug-of-war. HeCS's hope is that this model will eventually prove applicable to galaxy clusters that are distant on our horizon—giving us access to even deeper mysteries of our universe and the role dark energy plays in it.

mass

~~give mass~~

most important is looking @ mass @ each radius, as we get further out, and that comes all from velocity data from spectroscopy

-Michelle Wallace, Western Washington University

short ¶s → can cut and paste
don't split single points

"weight gain" → very rough analogy

→ linking that to growth stages

" current understanding of universe is structures go thru growth, → final growth spurt

Fifth Draft

May 2012. A team of astronomers with the Hectospec Cluster Survey (HeCS) and MMT Observatory in Arizona has estimated the ultimate sizes of 58 nearby galaxy clusters. Their findings show that the fate of these clusters is to approximately double in size before dark energy halts their growth forever, turning them into increasingly isolated "island universes."

According to our current understanding of cosmology, our universe is populated by astronomical structures that grow over time. We can think of these structures as being "glued" together tightly by gravity, a force which also causes them to grow by pulling more material—such as stars, gas and dust—into them.

Galaxy clusters are the largest astronomical structures held together by stable or "relaxed" gravitational bonds. As such, they present unique opportunities for studying large-scale structures in detail.

Like snowballs rolling down a hill, galaxy clusters grow over time by capturing more and more nearby galaxies with their gravitational pull. However, dark energy will eventually cause galaxy clusters to stop snowballing in size. Though we know very little about the mysterious force of dark energy, we have observed it in a cosmic "tug-of-war" with gravity—and galaxy clusters lie smack in the middle of the fight.

While gravity helps stabilize clusters by keeping mass tightly glued together, dark energy is pushing the universe to expand at an ever-increasing rate, making it harder for gravity to essentially "hold onto" that mass over time.

The HeCS team set out to discover just how much of that material actually *will* be "held onto" by gravity in the future. Conducted by Kenneth Rines, Margaret J. Geller and Antonaldo Diaferio, the study found that all clusters will eventually be "holding" twice their current masses.

In comparison, most studies to date have focused on determining the mass contained within what's called the virial radius of galaxy clusters. Basically, this is a measurement of clusters' current sizes. But with this study, Rines and his colleagues have estimated the total mass that galaxy clusters will *add* to their current sizes before dark energy denies them any further growth.

Turning to the "infall regions" of 58 nearby galaxy clusters, then, the team has determined the total amount of material that will become gravitationally bound to each cluster before dark energy wins its cosmic tug-of-war. After that time, no more galaxies will be able to "fall into" that cluster's gravitational control. And once this happens, the cluster will essentially become an "island universe" as the rest of the world zooms further and further away from it due to the expansion of the universe.

Of course, we have plenty of time before this actually happens. It's taken the age of the entire universe for galaxy clusters to accrue their current sizes. And again, according to this study, each cluster will *double* in mass before it becomes an isolated world.

To arrive at this figure, Rines' team selected nearby clusters from the Sloan Digital Sky Survey x-ray catalog. The MMT telescope was then used to obtain optical spectra for each galaxy, revealing its velocity. (Optical spectroscopy shows how light waves are stretched and compressed by the movement of stars and galaxies.)

Next, a method called the caustic technique was used to determine which galaxies will eventually fall into a cluster's gravitational stronghold. In basic terms, we can think of this technique as an analysis of "escape velocities." Just as rockets are able to escape Earth's gravity by traveling at high speeds, fast-moving galaxies on the outskirts of clusters can avoid eventual gravitational capture because of their large velocities. By measuring these galaxy velocities at different distances from the cluster center, astronomers can determine how many galaxies are traveling slowly enough to eventually be captured by the cluster's gravity.

Detailed observations like these are uniquely possible on nearby galaxy clusters. The hope of the HeCS team, however, is that this model will prove applicable to the most distant clusters on our horizon. If that ends up being the case, we may hold the key to even deeper mysteries of our universe, and the role dark energy plays in its ultimate fate.

-By Michelle Wallace

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