Dear Friends,

It has been an eventful year, and I am pleased to report that I have completed my first year as Department chair without doing undue harm to the Department. This year has seen noteworthy accomplishments by our faculty. Professor James Houck was awarded the Joseph Weber Award for Astronomical Instrumentation by the American Astronomical Society in recognition of his important achievements in inventing new detectors for astronomical observations of the Universe at infrared wavelengths. Professor Rachel Bean has been named a Cottrell Scholar by the Research Corporation, an appointment that recognizes faculty that excel both in research and teaching early in their careers. Closer to home, Professor Peter Gierasch and Senior Research Associate Don Banfield received a Faculty Innovation in Teaching grant from the University for design and implementation of a rotating fluid tank that can be used to teach undergraduate and graduate students the subtle behavior of rotating fluids, physics that underlies many phenomena of interest to all of us—such as the weather!

Dear Friends:

Summer is here already and soon in August the students will be back. In our environment, the passage of time never stops. In an environment close to a black hole, however, a distant observer will measure time slowing down, and theoretically time stops at the black hole! This is an amazing universe and the nature of time is still a big mystery.

In this issue of Orion, graduate student Andy Lundgren describes some of the peculiar physics of black holes. Professor Peter Gierasch writes about Jupiter and Professor Martha Haynes’ article shows how effective she has been in creating opportunities in astronomy for young women.

Professor James Bell reminds us all of the major planetary astronomy meetings that will take place at Cornell the week of October 13, for which you have all been invited.

The inaugural meetings of the Friends of Astronomy took place at Cornell in October 1992.

Arp 272, also known as NGC 6050 and IC 1179, lies some 450 million light-years away in the Hercules Galaxy Cluster. The collision and eventual merger of the galaxies may offer us a glimpse of the far future collision between Andromeda and the Milky Way but, because the space between stars is so great, it is unlikely it will result in stars colliding with each other. (NASA, ESA, Hubble Heritage)

Continued p. 2

Dear Friends............................1
Greetings .................................1
Thanks to the Friends! ............2
The Temperate Black Hole ..................3
Wet and Dry Ice on Mars .........4
Women in Astronomy ............6
Jupiter: An Update after the Galileo Mission ....8
Barbara Asks! ........................10
Plans on Track for AAS/DPS Meeting at Cornell this October ..........11
Books in Science and the Universe ..........12
Yervant’s Critical Thinking Corner ..........12

Summer 2008

Continued p. 2

Editor
Patricia Fernández de Castro
pf46@cornell.edu
The Department also faces significant challenges as it moves toward the future. The Cornell-Caltech Atacama Telescope project, directed by Professor Riccardo Giovanelli, hopes to raise funds for an engineering study to commence toward the end of 2008. The Arecibo Observatory, under intense pressure from the National Science Foundation, is seeking ways to ensure its continuation as a front line facility for radio astronomical research. Professor Donald Campbell assumed the directorship of the National Astronomy and Ionosphere Center, which administers the observatory, June 1, 2008, replacing Dr. Robert Brown, who oversaw the center for the past five years. We are all grateful to Bob for his able stewardship of NAIC, and wish Don success in this important position.

Have a great summer!

Ira Wasserman

Contributors

James Bell
Professor of Astronomy

Barbara Burger
Founding member, Friends of Astronomy

Patricia Fernández de Castro
Editor

Peter Gierasch
Professor of Astronomy

Martha Haynes
Professor of Astronomy

Andrew Lundgren
Graduate Student, Department of Physics

Peter Thomas
Senior Research Associate

Department of Astronomy

Yervant Terzian
The David C. Duncan Professor in the Physical Sciences

Ira Wasserman
Chair, Department of Astronomy

About 165 years ago, the southern star Eta Carinae exploded, becoming the second brightest star in the night sky. The outburst appears to have created the Homunculus Nebula, pictured above in a composite image which shows, in its center, the purple tinted light reflected by Eta Carinae and, around it, expanding lobes of gas bisected by jets emanating from the central star. Eta Carinae continues to undergo unexpected outbursts. Its high mass and volatility make it a candidate to explode as a spectacular supernova sometime in the next few million years. (N. Smith, J.A. Morse (U. Colorado) et. al, NASA)

Greetings

and the first Orion Newsletter edited by Patricia Fernandez de Castro appeared in the spring of 2002. Our Department has enjoyed this ‘Friendship’, we thank you for all your contributions and look forward to an exciting future with the stars.

Cordially,

Yervant
The classic picture of a black hole is that of a burnt-out husk of a star, collapsed to an unimaginably dense singularity, so dense that light cannot escape. What possible connection could this kind of object have with thermodynamics, which studies temperature, heat, and the efficiency of engines? To find out, I will first review what a black hole is. Since black holes seem to violate the Second Law of Thermodynamics, I will then define entropy and recall this important law. A better understanding of black holes shows that even they obey this fundamental law of Physics.

When a star runs out of fuel and starts to collapse due to the force of gravity, there are many possible outcomes depending on the size and type of star. Our sun cannot become a black hole, but many of the more massive stars will end their lives in a supernova, a tremendous explosion which ejects radiation and matter outward while the core of the star collapses to form a very compact object. Under some conditions, this object is able to stop its collapse and becomes a white dwarf or neutron star, with a mass similar to the sun packed into a radius of either Earth or Manhattan, respectively.

Other times, when the collapsing mass is very large, the object is not able to stop its collapse and all of its matter falls into the center, forming an infinitely dense singularity. This is what we would see if we were falling in with the collapsing matter. However, let us instead watch from a safe distance. What we see is that a surface forms when the matter becomes compact enough. This surface is the event horizon of the black hole, and it defines a region where the gravity is so strong that not even light can escape. Past this point, we do not see the matter inside the event horizon, and so it is best to think of the black hole as being defined by the event horizon. It is a surface in space, which does not emit any light, and since we no longer see any of the matter inside, we can think of the black hole as an entity made of pure gravity.

Let’s now define entropy, starting with familiar objects before we tackle black holes. Entropy measures the disorder of a substance at the atomic level, and can also be thought of as the amount of information needed to precisely describe the positions and motions of the atoms. A crystal has low entropy because the atoms are arranged in a nice regular, orderly shape. The hot gas inside a star has high entropy because the atoms are moving very randomly and are disorderly. The Second Law of Thermodynamics says that total entropy never decreases; disorder can stay the same, or it can increase. Examples are a piece of wood burning to ashes or kernels and oil turning into popcorn and steam; both are examples of entropy increasing, which cannot be undone. How then can life, which is a very ordered state, form? The answer is that life is a local decrease in entropy, balanced by an overall increase in entropy elsewhere. All life produces waste that carries away excess entropy. The total entropy always increases.

When a black hole is formed, it very quickly settles into a final state described by only the mass $M$, the amount of spin $J$, and the electric charge $Q$. Because stars have as many positive charges as negative, in practice real black holes have zero charge (although we could give a black hole a charge

**The Temperate Black Hole**

*When not doing physics, Andy Lundgren likes to play Ultimate frisbee, bluegrass guitar and board games with complicated rules.*

---

In this illustration, gravity draws gas from a companion star onto a black hole in a swirling pattern. As the gas nears the event horizon, a strong gravitational red shift makes it appear redder and dimmer. When the gas finally crosses the event horizon, it disappears from view; the region within the event horizon appears black. (NASA Science News)
Ithaca is nestled in what might be called the periphery of Earth’s seasonal north polar cap, which is composed of frozen water. While winter effects abate in the summer, at high latitudes and high altitudes there are permanent reservoirs of solid ice that are crucial to Earth’s climate workings. On oceanless Mars, the winter scene is quite different: instead of a trace atmospheric constituent precipitating at the poles, about one fourth of the carbon dioxide (CO$_2$) in the atmosphere freezes out in the winter, becoming “dry ice” (Figure 1). This covering extends nearly halfway to the equator, and as a result it was seen by early telescopic observers, who attributed this seasonal bright polar covering to water ice; only well into the 20th century was it inferred to involve CO$_2$. In fact, major confusion existed about the composition and density of the Martian atmosphere until the 1960’s, when spacecraft flybys returned data showing a thin, CO$_2$-rich atmosphere, and conditions precluding surface liquid water. While these findings disappointed those hoping to find obvious life forms, they started to give a more accurate picture of the geology and atmosphere of Mars. Explaining a planet that was so earth-like, yet very different, became one of the leading challenges for planetary science.

The Viking landers, arriving at Mars in 1976, gave direct analyses of its atmosphere, and watched its weather for more than a Mars year. Weather on Earth is made particularly complicated by the oceans, and their role in transporting and storing heat. With no oceans and a thin atmosphere, Martian temperatures and even details of weather follow the solar position both daily and seasonally far more closely than they do on Earth. In addition, because Mars has an eccentric orbit (its distance from the Sun varies by about 20%) and it is closest to the Sun during its southern hemisphere summer, southern winters are colder and longer than those in the north. Does all this seasonal coming and going of polar frosts have any lasting effect on Mars? Does it make any difference for its solid body “geology”? While they are nearly a fourth of the total atmosphere, the winter ice deposits have only a maximum thickness of about a meter, if solid ice. If they are fluffier, they could be thicker. This material goes away every spring; it does not form glaciers that then plow up the landscape and make real landforms in the solid rocks.

But while the CO$_2$ seasonal ice routinely goes away, there are distinctive polar landforms, and some summertime polar ice (the “residual” caps) indicates the polar climate does indeed have a geological effect.

The most massive of the polar features are domed, layered deposits centered on both poles, several hundred km in area and up to 3 km deep (Figure 2). These mounds are largely made of water ice with some admixtures of mineral matter (“dust”) that has the typical Mars red color. These deposits are thus close, but not perfect, analogies to Antarctic and Greenland ice sheets. Although both are dome-shaped, the terrestrial ice accumulations are near their melting points and are actively flowing. The Martian ones are much colder, and with dust additives, apparently do not flow in a way that has any substantial effect on their forms. It has been thought for a long time that these large piles of material could not be CO$_2$ ice as they would deform and essentially collapse under their own weight. However, it was not clear if these “polar layered deposits” were 99% ice or 99% mineral grains with a small amount of ice. Radar instruments on board both Mars Express mission and Mar Reconnaissance Orbiter have shown that they are mostly water ice.

The deposits at the poles thus represent long term cumulative effects of freezing small amounts of water from the Mars atmosphere. Water ice deposition at the poles implies there was some water available to be picked up.

Continued p. 5
Wet and Dry Ice on Mars

elsewhere. Because this can be a slow process (that is, the ice deposits at the poles are millions of year old), there do not need to be lakes feeding these deposits. In fact, the recent budget for the polar water ice is unknown: it could be accumulating slowly or losing slowly.

More fundamental than the current water ice budget at the poles is the problem of why residual ice in the north is water ice, and in the south is CO$_2$ ice. The question is not one of a water ice balance, but of a CO$_2$ ice budget.

This takes us to smaller, but possibly diagnostic, polar features: the “residual caps.” The northern polar cap loses its CO$_2$ ice in summer to reveal water ice, which in all appearances merges with the ice-rich layered deposits below it. When the surface temperatures of the south polar residual cap were measured, it was clear that it was CO$_2$, rather than much colder ice water. This posed a problem in climate and physical chemistry: could this be an exposure of a large reservoir of ice that maintained the pressure of the Mars atmosphere of CO$_2$? This remained something of a possibility until 2000, when the newly arrived Mars Global Surveyor’s cameras returned high resolution images that showed the CO$_2$ covering was only ~10 m thick, had a bizarre collection of depressions and textures, and was eroding year-to-year (Figure 3). Combined with other spacecraft data, it is now clear that the south residual cap is a collection of layers of dry ice sitting on a largely water ice/dust mixture, as in the north.

As on Earth, exposures of layers and erosional forms lay out the history of this deposit. The first two years of observation by Mars Global Surveyor showed that the distinctive “holes” in the south residual cap were expanding. Depressions in the thinner layers expanded at about 2 m/Mars year, and those in the thicker units at about 3.5 m/year. Such changes suggest something has been changing in the Mars climate. Perhaps more perplexing is the implication that two different forms of material are involved, i.e., mean different ice grain sizes, admixtures of dust, or porosities. Since there is no obvious summer accumulation of the CO$_2$ ice, the south residual cap appears to be shrinking, losing CO$_2$ to the atmosphere. The effect on the overall atmosphere, though, would be small as the whole deposit at the south pole is equivalent to only ~2% of the total Mars atmosphere.

Yet something has been changing. The erosion rates and sizes of depressions and the stratigraphic relations (what covers what) suggest that there have been a few episodes over the last 100-150 Mars years of unusual deposition of dry ice at the south pole, with erosion being the “normal” state. We are still investigating the climatic changes that induce such variations, including the physical makeup of the ice deposits. How porous is this material? And how much snows out and how much condenses directly on the ground? Small admixtures of dust can affect the properties of the deposit. A notable feature is that the erosion does not seem to occur on the top surfaces of the layers. The upper surfaces seem stable on the scale of ~100 Mars years. Rather, retreat of the steep slopes, once initiated (how?) is the major method of removal of material. As in many situations, exceptions highlight the rule: a few parts of the south residual cap apparently have simply collapsed, and, even more perplexing, left behind debris. What debris is left behind when CO$_2$ ice sublimates?

Repeat imaging of each summer’s changes (about every 2 earth years), and spectral data interpreted for indications of components other than CO$_2$ and for variations in grain sizes provide us with the data to investigate the south residual cap. Many more questions remain to be answered about the poles. This article focused on the last 10 m of polar deposits; the 3 km of ice and dust are even greater challenges to interpret!

-Peter Thomas
This July marks the 30th anniversary of my arrival in Arecibo as a postdoctoral scientist, my first job after receiving my Ph.D. I found myself on a professional staff comprised entirely of men, all good friends (and one, my husband, now Professor Riccardo Giovanelli). As an undergraduate at Wellesley, I was surrounded by other capable and wonderful women (none of whom are current presidential candidates; I am a bit younger!), but my post-undergraduate career I have frequently been an “only” or even “first”, female staff scientist, director of a major telescope facility, tenured faculty, board chair. At the same time, during the course of those 30 years, a transformation has taken place. Today, the situation of gender representation is much improved among the graduate students and at least noticeably better among the professional researchers. The undergraduate astronomy major typically has at least as many women among its graduating class each year as does the physics major, which graduates many more seniors. I see more women every day; we discuss scientific discoveries, issues associated with computing and instrumentation, and also, families. It’s, for me at least, a friendlier working environment.

This page, counterclockwise from top center:

Martha Haynes, with the Arecibo L-band feed array (ALFA), before the array was installed on the Arecibo telescope. Martha and Riccardo Giovanelli lead the Arecibo Legacy Fast ALF A Survey to conduct the first-ever census of atomic hydrogen in and between galaxies within a volume of the universe large enough for cosmological applications.

Katie Jore (Ph.D. 1996) and U. Wisconsin Stevens-Point under-graduate Liza Piltz at Arecibo for the Undergraduate ALF ALF A workshop in January 2008.

Kim Nguyen (CU’10) learning to process ALFALFA data during the undergraduate workshop. An astronomy major, Kim will spend her junior year at the University of Durham before returning to complete her project on the most massive galaxies detected in the ALFALFA survey.

Sabrina Stierwalt (current Ph.D. student) helping to remove the cover from the ALFA instrument in the Gregorian dome receiver room in Arecibo. This year, Sabrina received the Buttrick-Crippen fellowship from the Knight Writing Institute; she taught a very popular freshman writing seminar, Astronomy 109, “The Birth of the Universe” during the spring semester. Her research focuses on the dwarf galaxies discovered by ALFALFA and she hopes to complete her Ph.D. degree in summer 2009.

Next page, clockwise from center top:

Kristine Spekkens (Ph.D. 2005) and Martha Haynes conducting early test observations with ALFA in the control room at Arecibo in Fall 2004. After receiving her Ph.D., Kristine

Women in

Martha Haynes is a radioastronomer and a pioneer in the field. After her arrival in Arecibo, she has led numerous projects and contributed significantly to the field of radioastronomy.
During my Cornell career, I have had the pleasure to work with a lot of women undergraduate and graduate women. I now have the pleasure to see how well they are succeeding in their own careers. Jackie Hewitt, my first summer REU student, when I was a postdoc at Arecibo, is now the Director of the Kavli Institute for Physics at MIT. I remember being a bit shocked when Jackie introduced me to her first summer undergraduate assistant as his “astronomical grandmother.” But it is true, and there are now many more of them, many members of the ALFALFA survey team.

-Martha Haynes

Karen Masters (Ph.D. 2005) and Liese van Zee (Ph.D. 1996) during an observing run at Kitt Peak Arizona. After completing her Ph.D., Karen has been a postdoctoral researcher at the Harvard-Smithsonian Center for Astrophysics. This summer she will move to the Institute of Cosmology at the University of Portsmouth; she has just been awarded the Peter and Patricia Gruber Foundation Fellowship of the International Astronomical Union. Liese is associate professor of astronomy at Indiana University, the same department where Martha (and coincidentally, Riccardo and Yervant!) also received their Ph.Ds.

Sabrina Stierwalt (current grad student) and Lamarr Parsons (CU ’09) during the undergraduate ALFALFA workshop. Lamarr is an astronomy major and a Mellon-Mays fellow studying the rotational properties of galaxies detected by the ALFALFA survey.

Becky Koopman, Lisa Wei (CU ’04) and Barbara Catinella (Ph.D. 2005) conducting observations in the control room at Arecibo in April 2004. An associate professor of physics and astronomy at Union College, Becky has spent a study leave and a sabbatic year at Cornell and is currently the head of the ALFALFA undergraduate team. Lisa is a graduate student in the Department of Astronomy at the University of Maryland and hopes to complete her Ph.D. degree in 2009. After receiving her Ph.D., Barbara was a postdoctoral researcher at the Arecibo Observatory before joining the staff of the Max Planck Institut fur Astrophysik in Munich, Germany in 2007.
Jupiter: An Update after the Galileo Mission

As a researcher and a teacher, Peter Gierasch is a leading force in the field of planetary atmospheres and climate.

If you imagine building a planet by adding mass bit by bit until gravity holds it together, you will have a fairly accurate picture of the structure of a terrestrial planet or an asteroid. These are rocky bodies, and the more the mass, the larger the radius. A giant planet like Jupiter is built differently in two respects. First, instead of only the rocky compounds, its composition includes the volatiles, most abundantly hydrogen. The mix is much closer to the sun’s than to the inner planets’. The second difference is that as you added mass bit by bit, you would reach a critical point, beyond which addition of more mass would lead to a shrinking size. This paradoxical behavior was predicted and explained in a seminal paper in 1969 by Cornell’s E. E. Salpeter, working with H. S. Zapolsky. As more mass is added beyond a critical point, the increased pressure in the interior crushes the material, and shrinking is the consequence. Both Jupiter and Saturn are near this theoretical maximum, which is why they are similar in size (Saturn is 14% smaller) even though different in mass by more than a factor of 3.

However, the collapse and compression that led to the formation of Jupiter caused high temperatures in its interior, and even though not important in the structure against gravity, the heat of formation is even now still escaping. As a consequence, Jupiter radiates to space about twice as much heat as it receives from the Sun. Its surface weather layer thus has two energy sources, heating from below and solar heating.

Jupiter is wonderfully photogenic and among the outer planets it is the preferred target for studies of atmospheric motions, heat transfers and meteorology. Its clouds condense and evaporate high in the atmosphere where there is little obscuring haze, making it easy to see the sharp edges of freshly formed clouds. Markers can be found and mapped, and velocities can be determined relatively easily from time-lapsed images of clouds. But in spite of the favorable conditions on Jupiter, for years there was not sufficient information to resolve the issue of how thermal energy is converted to kinetic in order to drive the east-west jets that we observe.

There are two qualitatively different possibilities. The most straightforward is a direct circulation hypothesis, with rising motion at the bright, heavily clouded ‘zones’ and sinking motion at the darker, relatively cloud-free ‘belts’. At each of the ‘zones’ there would then be divergence or spreading. Where gas moves poleward, it spins up, creating an eastward jet due to angular momentum conservation. On Earth, solar heating causes overturning (a Hadley cell) and the poleward drift of the upper branch of the cell produces jet streams. Before detailed observations were available, this was also the view about Jupiter’s jets. But when high quality imaging began to come in from spacecraft, it became apparent that more complicated processes were active. The most obvious were strong eddies, almost ubiquitous over the surface of the planet. It was difficult to understand how the jets even survived in the presence of such turbulence. Another puzzling observation showed that the bright zones, which are regions of rising motion, were relatively cool. If they were part of a simple Hadley circulation one would expect warm, not cool, air to be rising.

Advances in fundamental fluid mechanics helped to provide an answer, or at least an alternative hypothesis. Notice that the waves and eddies in Figure 1 have a somewhat peculiar appearance when compared to ordinary turbulence. The cloud markers are drawn out into long narrow streaks, rather than breaking into small eddies. Peter Rhines, an oceanographer, showed that in fluid motions constrained to be two dimensional, turbulent energy drives large scale flow, rather than breaking into smaller and smaller eddies and dissipating, as it does in three dimensional flow. This mechanism, if active on Jupiter, would cause jets to be driven by an eddy convergence of momentum at the poleward edges of zones, rather than by poleward drift together with angular momentum conservation. Rhines showed that in spherical geometry, jets would be produced in the form of symmetrical currents at constant latitudes, with amplitudes and spacings consistent with those observed on Jupiter and Saturn.

Figure 1. Jupiter viewed from the Cassini spacecraft en route to Saturn. Note especially the long sinuous cloud structures produced in turbulent regions. (NASA/JPL/Space Science Institute)
The configuration would require momentum pumping by some new source, not yet discussed, that would also need to supply energy. We know that ultimately the energy to drive all activity on Jupiter is heat, whether from the Sun or from Jupiter’s interior. But if the energy for the major jets and currents comes from mechanical stirring, we have two new questions about the outer planets. Why, in their three dimensional atmospheres, do motions mimic those in a two dimensional spherical shell? How does thermal energy get transformed into small scale mechanical mixing, to drive turbulence that can become the large-scale jets?

The former question is not answered yet. We may need more observations of the layers beneath the clouds in order to answer it. Eventually we may have a flotilla of deep probes or powered drones for this purpose. But the small scale energy source has indeed been verified, and a large part of the work was carried out at Cornell. By examining puffy, bright cloud regions with a range of camera filters, and doing this with time delay for motion study, cloud structures like that illustrated in Figure 2 were found. The highest layers were found to be diverging away from the top, consistent with a strong updraft at the center. The deepest layers were found to be near the water condensation level, where the temperature is about 280 K. Finally, when the regions were targeted for camera shuttering on the night side of Jupiter just a few hours after the day-side cloud mapping imagery, there were found to be bright spots of light, variable in a time of a minute or less, which could only be lightning. The result of this campaign to understand energy sources on Jupiter is the sketch in Figure 3. It is a massive thunderstorm, three to five times higher than anything on Earth. The occurrence frequency in the Galileo images, it has been estimated that the majority of the internal heat might be transported through the surface weather layer by these storms.

-Peter Gierasch

The Temperate Black Hole

by shooting electrons into it). The black hole is described by two numbers (M and J), which are not enough to describe the position of even one atom in a star! The problem we face now is that if a black hole can be described by two numbers, it has very little disorder. Forming a black hole seems to decrease entropy, which is a crime against the Second Law of Thermodynamics. However, gravity by itself does not tell the whole story. Quantum mechanics has to be added to the mix to show that the Second Law is not actually violated, because black holes in fact have quite a bit of entropy.

Quantum physics has shown that, unexpectedly, the entropy of a black hole has to do with gravity and is proportional to the area of the event horizon. If a star forms a black hole, the entropy of the black hole (calculated from its area) is much larger than the entropy of the star from which it came. If two black holes merge, the area of the new black hole cannot be less than the sum of the two originals, so the entropy of the new bigger black hole increases. A star has no event horizon so its entropy is due to the disorder of its atoms; each square centimeter of an event horizon has disorder in the gravitational field, which is what gives black holes their entropy. Black holes should also have a temperature, and if they have a temperature they should radiate. Stephen Hawking showed that quantum mechanics predicts that black holes in fact radiate very weakly, and the radiation corresponds to a temperature which is typically extremely low but not zero. The calculations of the temperature and entropy of black holes fit in beautifully with the rest of thermodynamics, but there is still a great amount of work to do. Exactly what disorder the entropy corresponds to is not known. Quantum fluctuations in spacetime must be the source of the disorder, but we don’t yet have a quantum theory of gravity which explains these fluctuations. This is a focus of intense research. When results are published, it will be exciting to see what surprises gravity has in store for us.

-Andrew Lundgren
Q. Although Dirac stated that “it is more important to have beauty in one’s equations than to have them fit experiment,” a conclusion reached by other scientists, what exactly is it that constitutes a concept of beauty in a scientific theory and set of equations?

A. I am not a big fan of the concept of beauty as attached to the laws of nature. As Barbara’s question implies, beauty is a fuzzy concept. In science, as in life, it is good to remember the old saying, “Beauty is in the eye of the beholder.”

Let me give a well-known, but misunderstood, astronomical example.

Long ago, Ptolemy constructed a system for describing the orbits of the planets known to him. His Earth-centered model involved circles revolving on circles revolving on other circles—we call that the epicycle theory. Leaving aside that there are allegations that Ptolemy fudged his data a bit, there is general agreement that this is a pretty ugly if not contrived model for the orbits of the planets.

On the other hand, Copernicus composed a model in which planets move on circular orbits with the Sun at their center. Many people think of this as a beautiful theory. The only problem with it is that it is wrong. The planets do not move in circles around the Sun as their center. They move on ellipses, which are elongated like footballs, and the Sun is not at their center either. This is the first of Kepler’s three laws. Not only that, but the Ptolemaic model, as ugly as it may seem, is in fact a correct description of planetary orbits as seen by an observer on Earth.

This well-known story illustrates the pitfalls of applying some notion of beauty to the nature of the Universe. We often like models involving simple, highly symmetric shapes, like spheres or circles, and equate beauty with simplicity. Unfortunately, there is no physical law dictating simplicity.

However, the continuation of the story does reveal that there is a deep, underlying symmetry to the solar system: the gravitational force law is highly symmetric. The key came from Kepler’s two other laws, again derived from the data. His second law says that each of the planets, as it revolves around the Sun on its own, personal ellipse traces out “equal areas in equal times.” For example, consider Mercury, which orbits on a pretty elongated ellipse. Start at some point A in its orbit. Wait, say, a day, by which time Mercury has moved to a point B. Compute the area formed by the arc of the orbit between points A and B and the lines from A and B to the Sun. Then wait another day, by which time Mercury moves to point C, and compute the area formed by the arc of the orbit and the lines from B and C to the Sun. The areas are the same! Kepler’s third law says that for any planetary orbit, the square of the period of the orbit is proportional to the cube of the size of the orbit.

What do Kepler’s laws mean? Newton explained them all in terms of his law of universal gravitation, in which the force of gravity between any two bodies points along the line between them and has a strength that obeys the “inverse square law,” that is, diminishes like one divided by the square of the distance between them.

Once he had invented calculus, Newton could show that his law of gravitation allowed only three types of orbits corresponding to the shapes of so called conic sections: they are either parabola or hyperbola, both of which are unbounded, or ellipses, which are bounded. Thus, the planets, which are bound to the Sun, must move on ellipses. It is possible to have a circular orbit, since a circle is the un-elongated version of an ellipse, but that is a contrived circumstance requiring very special adjustment of the energy and angular momentum of an orbit. Not surprisingly, then, none of the planets moves on a precisely circular orbit.

Thus, the force is what has a simple structure, not the planetary orbits. This is an example of a deep idea in how physics describes nature: the underlying forces may obey some symmetry but the actual state of the Universe governed by them may not show the same symmetry. In the case of Newton’s law, the force has circular symmetry, but the implied orbits are not circles.

Even though it took Newton’s genius to reveal the “hidden symmetry” behind the planetary orbits, Kepler’s accomplishment was equally transformative.
Copernicus, Kepler tried to represent the orbits of the five planets known to him in terms of highly symmetric geometrical shapes, the five Platonic solids, and in the course of his research he even discovered a new generalization of these polyhedra called Kepler solids. However, as beautiful as his mathematical construction must have seemed to him, Kepler abandoned his theory when the data did not support it, thus establishing data as the final arbiter for conjectures about the Universe.

I never met Dirac, but I heard him lecture in the mid-1970s, when I was a student. I imagine that he said something about beauty in science, since his famous equation for the quantum mechanics of electrons was a brilliant deduction based on simple symmetry considerations. However, I am sure that whoever introduced him mentioned that Dirac’s theory of electrons anticipated the discovery of the positron—the anti-electron—in cosmic ray experiments as well as the development of quantum electrodynamics, the most accurately confirmed theory in physics. As beautiful as Dirac’s reasoning may have been, his work would have been an elegant footnote in the history of modern physics without these experimental confirmations.
**Books in Science and the Universe**


The two authors were philosophy students at Harvard who decided to express their knowledge by writing this lively book. You will find profound philosophical insights related through clever anecdotes. Yes, you will laugh, you will stop and think critically, and you will enjoy yourself.

Among the topics discussed you will find chapters on logic, ethics, religion and language. Here I give you a taste of the book with a few short examples.

–The optimist: The glass is half full.
  The pessimist: The glass is half empty.
  The scientist: The glass is twice as big as it needs to be.

–Salesman: “This vacuum cleaner will cut your work in half.”
  Customer: “Terrific, give me two of them.”

–A scientist and her husband were out for a drive in the country. The husband says “Look, the sheep have been shorn.” She replies, “Yes, on this side.”

–A lawyer sends a note to a client “Dear Frank: I thought I saw you downtown yesterday. I crossed the street to say hello, but it wasn’t you. One tenth of an hour: $50.”

–A worried patient visited his doctor and told him “I am sure I have liver disease.” The doctor replied “You’d never know that, there is no discomfort of any kind.” “Exactly,” says the patient. “Those are my exact symptoms.”

The authors also quote the great philosopher Groucho Marx as saying “These are my principles; if you don’t like them, I have others.”

-Yervant Terzian

**Yervant’s Critical Thinking Corner**

A Sure Way to Win in Monte Carlo!

Suppose you are playing a game where you flip a coin or spin a roulette with only black and red slots. If the coin comes up heads, you win and you collect as much as your original bet. If the coin is tails, you lose your bet.

First Round: You bet $1. If you win, you get an extra $1. So you have won and you can quit (Sure Win). If you lose, then you have lost $1. You can play again.

Second Round: This time you bet $2. If you win you will collect an extra $2, so you will be ahead by $1 and so you can quit (Sure Win). If you lose, then you have lost a total of $3. You can play again.

Round Three: You bet $4. If you win you will collect an extra $4, so you are ahead by $1 and you can quit (Sure Win). If you lose, then you have lost a total of $7. You can play again.

Round Four: You bet twice what you bet in the previous round, that is $8. If you win, you get an extra $8, so you are ahead and you can quit (Sure Win). If you lose, then you continue to double your bet until your first win.

On the 8th round you have to bet $128. (To reach this stage you would have to have gotten tails 7 consecutive times! The probability of this happening is less than 1%.) So keep playing until your first win and then you can quit, with a Sure Win. There is no flaw in the logic.

In a real casino the odds are not exactly as above, because casinos put an upper limit to how much you can bet. If that limit is low, then after a few strings of losses, you may have to bet an amount larger than the casinos permit, so you will not be able to recover your losses. In addition, of course, you would have to have large sums of money available to double your bet each time you lose. If you have 10 consecutive unlucky tosses, then you have to bet $1024. (In a real roulette, the chances of winning are a bit less than above because other than the black and red slots there are also two green ones with zero numbers).

The process described above is also known as the “Saint Petersburg Paradox.”

**To view old Orions**

please visit