O R I O N

Newsletter of the Friends of Astronomy Cornell University

Greetings

Dear Friends of Astronomy,

This fall the football team didn't do very well, the hockey team is struggling, but the good news is that Astronomy at Cornell continues to be in great shape.

We are all awaiting the first release of data from SIRTF expected in mid-December. Reports are that the spacecraft and the Cornell IRS instrument are doing great and Jim Houck has been caught smiling during the past two weeks.

Steve Squyres, Jim Bell and their students have been spending long days and nights at JPL getting ready for the Mars landing in January. The first MER is scheduled at 11:35 p.m. EST on January 3 in Gusev crater—and then the excitement will really begin.

Speaking of excitement, I hope that many of you are planning to join us for the next special get-together for the Friends of Astronomy Yervant is planning for early June. It is rumored that many mysteries of cosmology, including perhaps the nature of mysterious dark matter will be elucidated. You won't want to miss this one.

The coming year promises to be an exciting one in many ways. Early in January we expect to announce an important next step in

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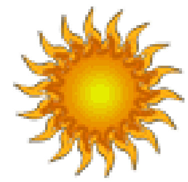
The Whirlpool Galaxy M51
Tom Boroson (NOAO)

Happy Holidays!



Dear Friends,

The astronomers at Cornell wish you happy holidays and a great and healthy 2004 year. In the Department, we're looking forward to the adventures of the two Mars Rovers, Spirit and Opportunity, which are scheduled to roam on Mars starting on January 4th and February 25th respectively. Last month, we celebrated the fortieth anniversary of the Arecibo giant radiotelescope, built by Cornell and operated by Cornell throughout this period. It has been a journey of adventure and discovery in radio and radar astronomy and atmospheric physics.

In the last few years, great advances have occurred in observational and theoretical cosmology. The Big Bang is still the basic hypothesis of the beginning of the Universe, but its details are being investigated and have yielded surprising new realizations. For this reason,

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Winter 2003

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http://www.astro.cornell.edu/

Shedding New Light on Dark Matter

Thirty years ago, astronomers studying other galaxies made the startling discovery that there is much more matter than meets the eye in spiral galaxies: the material in the outskirts of galaxy disks is moving more rapidly than the gravitational pull of the visible matter implies. To explain this conundrum a new type of substance, called *dark matter,* was invoked: by definition, it behaved gravitationally just like normal matter and yet was completely invisible, at least to the instruments of the time.

Today it appears that the contents of the Universe are more bizarre still: investigations of primordial bumps and wiggles imprinted on the cosmic microwave background (CMB) reveal not only that there is about four times more dark matter than visible matter on the whole, but that matter itself accounts for only a third of the energy density in the Universe! Though the nature of dark matter still eludes us, these observations constrain a key characteristic: dark matter must be cold, in that its random motions are small even in the hot early Universe (see *Barbara Asks!* in the Spring 2003 edition of Orion for more details). With this tenet in hand, theorists have constructed simulations that reproduce the properties of superclusters of galaxies and high redshift clusters with impressive accuracy. Indeed, this now canonical *cold dark matter (CDM) paradigm* is postulated to govern the formation and evolution of all structures in the Universe.

Ironically, the same type of galaxy studies that established the existence of dark matter now present the CDM paradigm with its greatest challenges to date. By plotting the rotational velocity of the material in a galaxy disk as a function of distance from that galaxy's center, astronomers can constrain its dark matter content both in the inner parts and outskirts of the disk. In doing so, a controversy known as the *cusp-core problem* has developed: while CDM theory predicts a *cusp* (a near-linear decrease with radius) in the central dark matter density distributions, those inferred from observations favor constant density *cores.* This issue is complicated, however, by uncertainties associated with deriving galaxy densities observationally. A critical question therefore remains: does the cusp-core problem signal the failure of the canonical CDM paradigm in galaxies, or can it be reconciled by some other means?

As a graduate student in the ExtraGalactic Group (or EGG; see http://www.astro.cornell .edu/Galaxy/egg.html for more information) at Cornell, I am completing a project with my advisor Riccardo Giovanelli that explores the latter of these two possibilities. The EGG maintains an enormous database of galaxy observations, which I mined to test the impact of optical observing techniques on the measurement of galaxy density distributions. As determined in previous studies, I found that the measured inner halo shapes for my sample were rather core-like, in stark contrast to CDM expectations. However, the computer simulations of my sample, which I conducted to understand the effects of observing errors and data processing techniques, demonstrate that one often measures a core in a galaxy that actually has a cusp! It therefore seems that, at least in part, the cusp-core problem is an observational artifact rather than a CDM crisis.

Despite its long history in galaxy studies and small victories in elucidating its properties along the way, our understanding of dark matter on galactic scales is still in its infancy. However, future observational and computing facilities promise to make the next few decades in extragalactic astronomy exciting ones. I am fortunate to have the opportunity to learn about this field at a premier institution like Cornell, and look forward to shedding new light on dark matter in the future.

- Kristine Spekkens '05

Greetings

Continued from p.1

bringing Cornell's Atacama Project—the building of a world-class telescope in Chile—closer to realization. Our astronomers also continue to lay plans for other future endeavors. Several members of our faculty are playing significant leadership roles in the international Square Kilometer Array (SKA) project and the complex NASA mission to return a sample of actual comet material for laboratory analysis here on earth.

As I write this our Fall Semester is coming to a close and our students, faculty and staff are looking forward to the holidays. 2003 has been a great year for Astronomy at Cornell. We expect 2004 to be an even better one. As we confidently look to the future, I want to express our gratitude to all our Friends of Astronomy for their continued interest and support and wish you one and all much happiness, health and wisdom for 2004. And don't forget to keep wondering about the mysteries and enigmas of the universe—that's one of the great joys of being alive. Deep down, we're all astronomers.

-Joe Veverka

WOULD YOU LIKE TO UPDATE YOUR E-MAIL?

Send a note to
Patricia Fernández de Castro
pf46@cornell.edu

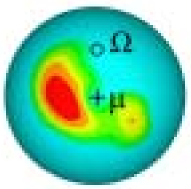
Looking at the Universe through a Numerical Telescope

Dr. Marina Romanova, with Professor Richard Lovelace and a group of scientists of the Keldysh Institute of Applied Mathematics in Moscow, was among the first to use numerical methods to understand complicated flows of matter into and out of magnetized young, dwarf and neutron stars, and out of the cores of galaxies that the best telescopes cannot observe

Looking at the sky with telescopes that can detect radiation at X-rays is like looking at a Christmas tree. We see many neutron stars and white dwarfs, which radiate in X-rays, blinking, blinking here and there. Regions of star formation are also constantly blinking, albeit somewhat slower.

We do know that many stars have strong magnetic fields. Now, there are hundreds of billions of stars in our Milky Way galaxy. Maybe a billion of them are either very young stars or very old stars, which have very strong magnetic fields. Young stars are those that are just forming from the gravitational collapse of interstellar clouds. They have strong magnetic fields with two poles, like our earth's, but much stronger, about a thousand times that of our sun. Interaction of matter with the magnetic field explains the complicated variability—the blinking—of these stars. As they mature, stars become less variable and less interesting, like our sun, which fortunately is not very variable in visible light. Its magnetic field is not very strong, and although it can make some events like solar flares and magnetic storms that we can detect from earth, it is a thousand times weaker than a young star's. At the end of their life, after they consume most of their nuclear energy, stars collapse and become either neutron stars, white dwarfs or even black holes. These collapsed star remnants conserve their magnetic fields, which measure about 10^{12} Gauss, a thousand billion times that of the Sun. This creates extreme conditions for matter to flow around the star; matter may then flow into the poles and out of the star to far distances.

Young stars



An example of the hot spots that form near the magnetic poles of the star (their shape, size and number may vary). **μ** *shows the magnetic pole and* **Ω** *the rotation axis or pole of the star.*

The remnants of protostellar clouds continue to rotate around newly formed stars. As the material rotates, it forms a disk that falls, spiraling slowly, into the star due to the star's gravity. How the gas flows towards the star is a very difficult problem to investigate especially when the magnetic axis is inclined relative to the equatorial plane of the disk. When the matter from the disk comes to an area of strong magnetic field (the magnetosphere of the star), it cannot go through it. Gravity is attracting it, however, so it tries to find a path to the poles of the star. When it comes to the poles it forms hot spots, and as the star rotates, we see the constant light of the star and additionally, on and off, light from the hot spots. That is why we see young stars blinking.

The light from the star thus appears to vary. It would be an easy story if the light varied with a regular beat. In reality, however, it is very complex because of the intricate interactions of the in-falling matter with the stars magnetic field. When matter accretes to the star through the magnetosphere, it forms complicated funnels (or streams of matter) that go above the magnetosphere. These funnels radiate light on their own and may also hide the light from the hot spots and from the star, adding to the complicated variability of the star (see picture on page 4). Numerical simulations help to understand this variability.

Older stars

The situation is very similar with old stars that have collapsed, either neutron stars or white dwarfs, which are coupled to a regular star (binary stars), in spite of the fact that their radii are hundreds of thousands of times smaller than young stars. In such cases the matter comes, not from the remnants of the protostellar cloud, but from the nearby star, and it also forms a disk which behaves like the disk around the young star. The variability of these stars, again, is determined by the interaction of the magnetosphere with the circumstellar disk and our calculations apply to these stars as well. Here again matter accretes to the poles forming hot spots, from where we see light.

Thus in both young stars and older compact stars the blinking is explained by the rotation of the magnetic poles and by the formation of complicated funnel streams between the disk and the star.

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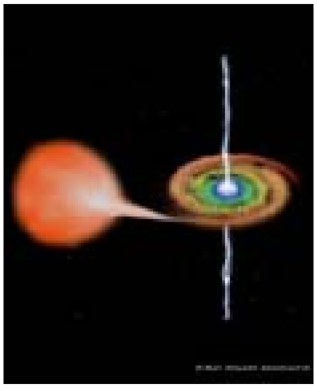

An illustratation of how an old, collapsed star in a binary system accretes matter from its companion star by forming a disk. The rotation and magnetic fields are responsible for the jets observed in X-rays. X-Ray Jets of XTE J1550, M. Weiss (CNX).

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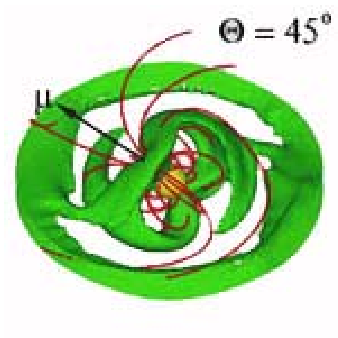
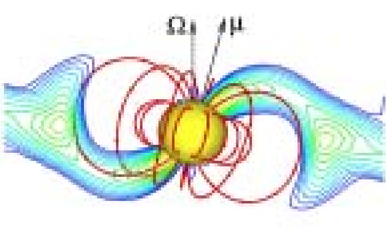


The flow of matter from the accretion disk (in green) around a star takes on different shapes depending on the inclination (Θ) of the magnetic axis (μ) relative to the rotational axis of the disk. The magnetic field lines are in red. US-Russia Plasma Astrophysics Collaboration.



This image shows a cross-section of the flow of matter towards a star. In red, the magnetic field lines; Ω represents the rotational axis and μ the magnetic axis. US-Russia Plasma Astrophysics Collaboration..

There is still another cause of variability in both young and old stars, the interaction of the outer magnetic field lines with the circumstellar disk. Because the star and the disk rotate with different rotation rates, the disk and magnetosphere of the star exchange momentum. The disk randomly accelerates or decelerates the star's rotation. We observe this as the spinning up or spinning down of the star. This interaction is also connected to changes in the accretion rates to the star and adds to the variability of the star, like a complex magnetized machine at work!

Outflows of matter

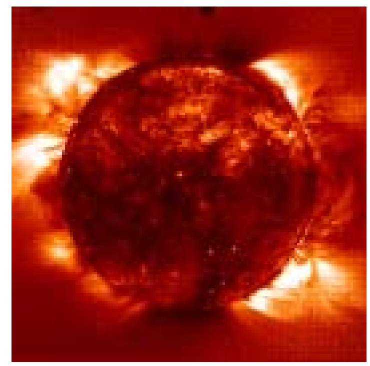
The interaction of matter with magnetic field may also to lead another phenomenon we study with our numerical simulations: the outflows or jets of matter which are observed from many systems, including young and old stars, and galaxies. These streams of matter, which go in opposite directions and to very far distances, constitute one of the most exciting phenomenon in astrophysics, but we still do not understand how they are produced. We think that outflows appear as a result of the interaction of the rotating matter of the disk with the magnetic field lines that thread it. When the disk rotates, if the magnetic lines are inclined, matter starts to go up from the disk, pushed by centrifugal and magnetic forces. The magnetic field acts like a wire that directs plasma upwards. We think this is how matter goes out and upwards from the disk. Later it is collimated either by the magnetic field lines or by the surrounding interstellar medium.

If the star rotates very fast, it might expel some matter outward on account of the so-called propeller (or Mixmaster) effect. When a star has just been formed, and again when it is old and collapses, it often rotates very fast, so the rotating magnetic field pushes away a fraction of the matter that is trying to accrete from the disk onto the star. Since it cannot continue in this direction, it goes outward as a jet.

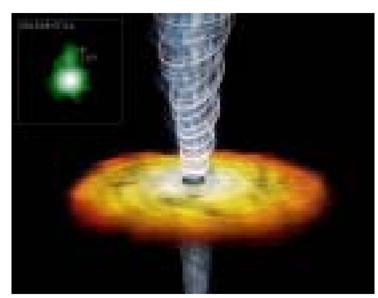
Similar jets are also observed from the centers of active galaxies with an active nucleus (one that radiates very brightly). In the center of galaxies there are very massive black holes[1] that are surrounded by a disk of matter that is rotating and streaming into it. The black hole and the disk are billions of times smaller than the galaxy, which is something like 100,000 light years across. What is amazing is that these jets stretch far away, often beyond the galaxy itself!

All these processes cannot be observed with a telescope directly. The Hubble Space Telescope can resolve objects that are small—it can see some disks and some outflows, but it cannot see what is closer to the star or the black hole because it would need to be hundreds of times more powerful to resolve these regions. With numerical simulations we can take into account that part of the disk and part of the jet which can be observed, but we can go deeper, to where telescopes cannot see.

Beginning in the 1990s Professor Richard Lovelace and I started the U.S.-Russia Collaboration in Plasma Astrophysics. We began to work to solve the complex magnetohydrodynamic equations with scientists from the Keldysh Institute of Applied Mathematics in Moscow, who specialize in numerical methods. Their input was critical because to solve complicated problems it is better to work in a group, where different specialists do different kinds of work. In recent years, in addition to continuing our



This image of the sun in extreme ultraviolet light shows the flow of hot (1,000,000º K) gas along the loops of the magnetic field of the sun. The magnetic field of young stars is of the order of a thousand times that of the sun. SOHO/EIT (ESA&NASA).



The Most Distant X-Ray Jet—an artist's rendition of an accretion disk rotating around an active galactic nucleus and a jet flowing out from it. A. Siemiginowska (CfA) et al., M. Weiss.

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Barbara Asks!

On the darkness of the night sky and the expansion of the universe

Q. *Why does it get dark at night, and is it getting darker?*

It may seem mundane that the night sky is dark. The darkness of the night sky is a fundamental clue that the Universe is expanding, and that the time since the appearance of the first bright objects—stars and galaxies—is finite.

A. Suppose instead that the Universe were infinitely old, and filled with stars. Then, when you look into the sky in any direction at all, your line of sight should fall on the surface of a star. As a result, each point on the sky should be as bright as the surface of a star. I would guess that not only would this make it hard to sleep at night, but it would also make us all go blind. In fact, the realization that the night sky should not be dark in an infinite Universe filled with stars is not new—that it is dark is called Olbers' Paradox, after H. W. M. Olbers, who lived from 1758-1840! Steven Weinberg, in his book on general relativity, also notes that the Swiss astronomer J. P. L. de Cheseaux noted the significance of the darkness of the night sky in 1744.

You might think that a possible resolution of Olbers' Paradox would be that the Universe is filled with dust or some other diffuse absorbing stuff as well as stars. It would indeed be true that the dust could obscure the light from distant stars along some, if not almost all, directions on the sky. This is the solution offered by Olbers and de Cheseaux, according to Weinberg. However, the dust would be heated by the light it absorbs, and eventually reach an equilibrium in which it re-radiates as much as it absorbs. In galaxies, this results in infrared radiation; in an infinite Universe, it is probable that the re-radiated light would be at shorter wavelengths, such as optical.

How does expanding Universe cosmology resolve the paradox? There are two key elements of the resolution. First, the age of the bright objects, such as stars and galaxies, is finite. (Indeed, the age of the Universe is also finite.) Thus, the number of bright objects to observe is no longer infinite, and therefore when you look in a particular direction on the sky, your line of sight need not end at the surface of a star. Moreover, the sum of the energy from the emissions of all of these stars is finite. Second, because the Universe expands, the color of the light from a distant object is shifted redward. This means that an object that would appear bright in the optical at a small relative distance would be bright in, say, the infrared at a great distance. The more remote the bright object, the redder it appears. Only a fraction of all of the optical light ever emitted by all of the stars that have ever existed since the Big Bang arrives at Earth as optical light. Expansion of the Universe shifts most of it to infrared, millimeter, and even longer wavelengths, which our eyes do not detect. Thankfully, this keeps the night sky dark, so we can sleep.

Our Galaxy in Stars, Gas, and Dust.
John P. Gleason, Steve Mandel.

The stars that we see visually in the night sky are all in the Milky Way, our own Galaxy. So, what we will see in the future depends primarily on how the stellar content of our Galaxy changes with time. Right now, we see stars with a whole range of different ages, from very young to very old. As stars age, they can suffer different fates. Some are massive enough to explode in supernovae, leaving behind compact remnants—either a neutron star or a black hole—that do not return **any** mass to the Galaxy for forming new stars. Others may form white dwarfs that usually just fade away and also do not return much mass to the Galaxy for forming new stars. As a result, the Galaxy eventually stops forming stars, and even the Milky Way will fade away.

Will the Universe keep forming new galaxies outside our own, with new star formation, that we can observe forever? The answer depends on how the Universe evolves into the future. Nowadays, we believe that the expansion of the Universe is accelerating. Whether it will accelerate forever is not known. If it will, then we can be sure that galaxy formation has already pretty much ceased. New star formation may eventually occur mainly when galaxies already in existence collide, much as the Milky Way and Andromeda will do some 10-15 billion years from now. Moreover, large galaxies will consume smaller ones for awhile, just as the Milky Way will eventually consume the Magellanic clouds. As long as colliding galaxies contain enough gas, each collision will trigger a burst of star formation. However, such collisions should become rarer as time goes on, and eventually the few galaxies that collide may have very little material left to form new stars.

Another limitation on what we might see in a perpetually accelerating Universe comes about because even as the acceleration proceeds to infinite age, the ages of the detectable bright objects tends to a constant limit. This means that as the Universe ages, these objects become redshifted more and more. The obvious consequence is that they become redder, but they are also becoming more "distant." Thus, they will dim, not only in the optical range, but in any wavelength range at all. The night sky would, in such a Universe, darken.

Various people have estimated the distance to which we could see bright galaxies in the future, assuming a perpetually accelerating Universe and

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Happy Holidays!

Cont. from p. 1

as many of you have suggested, we are announcing a one day FOA Symposium on Recent Adventures/Advances in Cosmology (at a popular level) on Saturday, June 5th, at Cornell. Topics will include an introduction to the Big Bang Model, new results: dark matter and dark energy, the anthropic principle, and string theory and cosmology. We shall also find time to have a presentation on the results from the Mars Rover missions. In addition, we are planning "a very special exhibit" for the Friends of Rare Scientific Books, including works by Copernicus, Galileo and Newton. The Symposium will begin with dinner on Friday, June 4, and will conclude with a banquet on Saturday night, June 5th. Detailed information and registration will be forwarded to you by the end of January 2004. Friends of Friends are also welcome!

Patricia and I send you our very best wishes. Happy holidays!

Cordially,

Yervant

On November 8-9 we were treated to a spectacular lunar eclipse. This picture, which was the Astronomy Picture of the Day, was taken a few kilometers outside of Cologne, Germany.
Markus Strassfeld <www.goldtech.de>

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A striking photograph of the Northern Lights as seen from Cornell's Hartung-Boothroyd Observatory last October 30.
Brian Kent '08.

Thanks to the Friends

Last October 16, Professor Bruce Balick, of the Department of Astronomy of the University of Washington, gave the Josephine Lawrence Hopkins Foundation Colloquium. His talk was entitled "Planetary Nebulae: New Laboratories for Astrophysics." Dr. Mario Livio, of the Space Telescope Science Institute, will give the Charles and Barbara Burger Colloquium on March 11, 2004.

This year three students were granted Yervant Terzian Fellowships: Elizabeth Bass '05 (Astronomy), Silbren Isaacman '05 (Physics) and Magdalena Preciado-López '05 (Engineering Physics).

CAU in Arecibo

Cornell Adult University has organized a trip from March 2 to 6 to Puerto Rico and the Arecibo Observatory that will be led by Professor Yervant Terzian. For more information, please call Carol Barrett at (607) 255-6260 or e-mail her at cab6@cornell.edu.

Barbara Asks!

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some plausible limitations on the brightnesses we can detect. The estimates all seem to agree that in something like another 100 billion years, we will not be able to see beyond the Virgo cluster of galaxies, to which we are bound (and may eventually fall into). It is astonishing that 100 billion years is not wildly larger than the current age of the Universe, about 13.7 billion years. Anthropic arguments often account for various cosmological coincidences, such as the comparable ages of stars and the Universe, by saying this must be so for us to be able to exist. In a perpetually accelerating Universe we can add that there is only a finite window in time when we could exist, discover that the Universe is expanding, and discern the nature of its expansion.

-Barbara Burger (for the question)
-Ira Wasserman (for the answer)

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Joseph Veverka
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Recent Friends Activities and Future Events

From left to right, Yervant Terzian, Maddy Handler, Steve Squyres and Barbara Burger. Photo: Chuck Burger.

Last June 23 a group of Friends met in Cape Canaveral to witness the launch of the Mars Rover Opportunity. The Friends had dinner at a local restaurant and heard Dr. Robert Sullivan discuss the planet Mars. They also participated in a banquet at the impressive Kennedy Space Center Saturn V Pavillion that featured Steve Squyres as one of the speakers. We were unable to see the launch of the Rover, because it was, unfortunately, delayed by inclement weather. Happily, Opportunity took flight at 11:18 p.m. EST on July 7th and is scheduled to arrive in Mars on January 25th. For mission updates, visit <www.athena.cornell.edu>.

There will be a Special Symposium for the Friends on campus on June 4th to 5th. The title of the Symposium is *Adventures in Astronomy: Recent Advances in Cosmology.* We hope you will be able to come!

Books in Science and the Universe

Our Final Hour by Martin Rees (Basic Books, 2003)

Sir Martin Rees is the Royal Astronomer of England, a celebrated Professor at Cambridge University and a very well respected cosmologist. His recent book, *Our Final Hour*, is a provocative analysis of our human future on the planet earth. He suggests that there is only a fifty percent chance that we will survive the twenty first century.

Rees argues that the inevitable progress of science and its resulting technology spell disaster for the human species. He thinks that our increasingly interconnected world is vulnerable to 'bio' and 'cyber' terror and error, and that lethal man-made viruses, or nanomachines out of control, can cause global havoc.

Maybe the fate of any intelligent and technological civilization on any planet in the universe is to destroy itself the moment it is able to do so, and maybe this is the reason why we have not seen or heard from anyone out there!

On the other hand, some feel that we shall be able to solve our problems and emerge a happy and everlasting species, wiser and more cautious.

-Yervant Terzian

Num. Telescope

Cont. from p.4

work with the Keldysh Institute, we have worked with many Cornell undergraduate students who work in the Astonomy Hewitt Lab on the numerical simulations and the graphics, and learn astrophysics, physics and math.

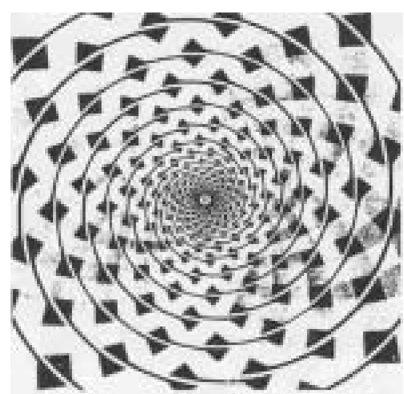
Our group was one of the first which developed methods for the solution of gas flows in magnetic fields. What we do is simulate real space with well-understood physics equations. We use the magneto-hydrodynamics equations, which are known and describe gas or liquid flows in terms of density, temperature, velocity and magnetic field in a three dimensional space. Since we know the parameters of the star and its magnetic field from observations, what we model is what would be observed with an as yet non-existent telescope. Thanks to the Cornell Supercomputer we can do our calculations as precisely as possible, to simulate real situations. I like to call our method a numerical observatory, because we see on the computer what we would see with a telescope if it could see a thousand times clearer.

Marina Romanova
with
Patricia Fernández de Castro

[1] With a mass equivalent to a billion solar masses.

Visit <www.astro.cornell/us-rus>

The Frazier Twisted Cord Illusion



Is this a group of concentric circles or a spiral?

Join us in a

Special Symposium

for the

Friends of Astronomy

on

Adventures in Astronomy:

Recent Advances in Cosmology

June 4th - 5th, 2004

Cornell University

Ithaca, N. Y.

Inquiries: pf46@cornell.edu
Program and registration materials will be available in January.

Yervant's Critical Thinking Corner

A bright young student, Ephthylus, wanted to study law with a very famous professor named Protagoras in ancient Greece. However, the student was poor and did not have the money to pay Protagoras for the lessons. Protagoras made a deal with the student; he said "I will teach you law and you do not have to pay me now. When you graduate and go into practice and win your first case, then you have to pay me."

Ephthylus graduated with high honors, but then decided not to practice law, and did not pay his teacher. Protagoras was upset and took him to court. Each defended himself.

Ephthylus argued that, if he were to lose this case, he would not have yet won his first case and would not have to pay, and that also, if he were to win this case, then it would mean he had won this case and would not have to pay either. So, he argued, lose or win he did not have to pay.

Protagoras said, "not so fast!" He argued, "if I were to win this case, it means I won and therefore Ephthylus should pay and, if I were to lose, it would mean that he won his first case and therefore he must pay. Also for me, lose or win he must pay."

This story has entertained people for centuries!