Star Dust

National Capital Astronomers, Inc. http://capitalastronomers.org

Volume 66, Number 6 | February 2008 | ISSN 0898-7548

February Speaker: Dr. Rhonda Stroud — "Nanoastronomy: Laboratory Analysis of Returned Comet Samples from the Stardust Mission"

Dr. Rhonda Stroud, Naval Research Laboratory, will present the talk "Nanoastronomy: Laboratory Analysis of Returned Comet Samples from the Stardust Mission" at the February 8 meeting of the National Capital Astronomers, 7:30 P.M., at the University of Maryland Observatory in College Park, Maryland.

Abstract

On January 15, 2006, the NASA Stardust spacecraft returned to Earth the first bona fide samples of a comet. Since then, scientists around the world have been working to characterize the elemental composition, structure, and isotopes of the comet dust. Because comets formed very early in the history of the solar system and at great distance from the solar nebula, the captured dust grains are relicts of the early solar system processes. Laboratory analyses performed to-date show a mixture of silicate minerals, iron sulfides and even some molecular organic material, but very little of the expected dust from stars predating the Sun. At the Naval Research Laboratory, we use transmission electron microscopy to image the cometary grains, including both inorganic and organic materials, at the nanoscale. I will present results from Stardust analyses and discuss the implications for our understanding of comets and the early solar system.

Biography

Dr. Rhonda Stroud received a Bachelor's Degree in physics from Cornell University and a Ph.D. in physics from Washington University in St. Louis. She came to the Naval Research Laboratory in 1996 as an NRC Postdoctoral Fellow and was converted to staff in 1998. In 2007, she became the head of the Nanoscale Materials Section of the Materials Science and Technology Division. Her research specialty is the application of transmission electron microscopy to the nanoscale analysis of materials, ranging from cosmic dust to fuel cell catalysts. She participated in the Stardust Mineralogy and Petrology, Crater and Isotope Preliminary Examination Teams, and now serves on the Stardust Sample Allocation Committee.

November 2007 Talk by Dr. Joan Centrella "Binary Black Holes and Gravitational Waves"

Reviewed by Dr. John Hornstein

At the NCA Meeting at the University of Maryland Observatory in College Park on November 8, 2007, Dr. Joan Centrella, Chief of the Gravitational Astrophysics Laboratory at the Goddard Space Flight Center in Greenbelt, Maryland. described gravitational waves, their production by binary systems of black holes, and current and upcoming attempts to detect gravitational waves.

What is a gravitational wave?

Dr. Centrella began by explaining what a gravitational wave is. It is a propagating disturbance in the local curvature of spacetime. Gravitational waves propagate at the speed of light. They are transverse, that is, their action is in the plane perpendicular to their direction of propagation. That means that a single elementary gravitational wave is polarized.

Like any transverse wave propagating at the speed of light, gravitational waves have exactly two independent polarizations, which can be expressed equally well either as two independent *linear* polarizations or as two independent *circular* polarizations. The action of polarized gravitational waves is a little more complicated than that of polarized light waves, which are the most familiar type of transverse waves that travel at the speed of light. Dr. Centrella illustrated the action of a linearly polarized gravitational wave by showing a movie of its effect on a cloud of freely falling particles that, prior to the wave's arrival, had been arranged in a circle in a plane perpendicular to the wave's direction of propagation. When the wave had one of the two independent linear polarizations, up-down distances expanded and left-right distances contracted, and then the reverse occurred a half cycle later. The same thing happened when the wave had the other linear polarization, but along axes that were inclined at 45 degrees to the first set of axes. (The ef-

(Continued on page 3)

Calendar of Events

The Public is Welcome!

NCA Home Page: http://capitalastronomers.org

NCA Mirror- and Telescope-making Classes: Fridays, January 11, 18, and 25, 6:30 to 9:30 P.M. at the Chevy Chase Community Center, at the northeast corner of the intersection of McKinley Street and Connecticut Avenue, N.W. Contact instructor Guy Brandenburg at 202-635-1860 or email him at gfbrandenburg @yahoo.com. In case there is snow, call (202) 282-2204 to see if the CCCC is open.

Open house talks and observing at the University of Maryland Observatory in College Park on the 5th and 20th of every month at 8:00 P.M. (Nov.-Apr.) or 9:00 P.M. (May-Oct.). The talks are non-technical. There is telescope viewing afterward if the sky is clear.

Dinner with NCA members and speaker: Saturday, February 9 at 5:30 P.M., preceding the meeting, at the Garden Restaurant in the University of Maryland University College Inn and Conference Center. See map and directions on Page 6.

Upcoming NCA Meetings at the University of Maryland Observatory in College Park, Maryland

Saturdays

February 9, 2008,
Dr. Rhonda Stroud, Naval Research Laboratory will give the talk "Nanoastronomy: Laboratory Analysis of Returned Comet Samples from the Stardust Mission"

March 8, 2008,
Dr. Drake Deming, GSFC/NASA, "Infrared Light From Extrasolar Planets."

April 12, 2008,
TBA

May 10, 2008,
Dr. Xiaolei Zhang, George Mason University," Gravitational Density Waves in Galaxies."

June 14, 2008,
Dr. Harold Williams, Montgomery College.

Please Get *Star Dust* Only Electronically

National Capital Astronomer members able to receive *Star Dust,* the newsletter of the NCA via e-mail as a PDF file attachment, instead of hardcopy via U.S. Mail, can save NCA a considerable amount of money on the printing and postage in the production of Star Dust (the NCA's single largest expense) and also save some trees. If you can switch from paper to PDF please contact Michael L. Brabanski, the NCA Secretary-Treasurer, at mlbrabanski@verizon.net or 301-649-4328 (home). Thank you.

The deadline for the March Star Dust is February 20. Please send your material to Elliott Fein by that date to ensure inclusion.

Send submissions to Elliott Fein at ed.fein @verizon.net.

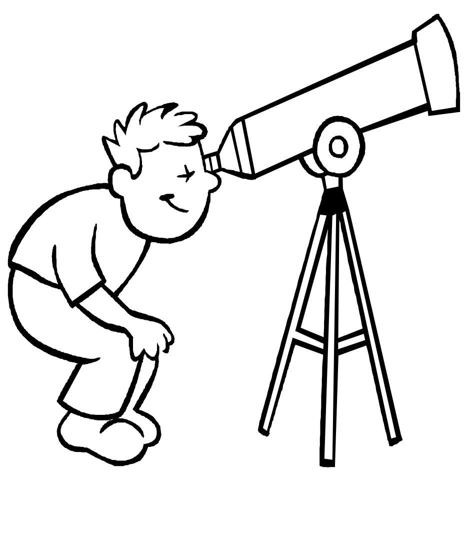
Articles submitted may be edited to fit the space available.

If a reviewer wants to have the speaker review the review, any corrections therefrom must be completed when the review is sent to me by the deadline. I need to have a final version by the stated deadline. Also, if a reviewer sends me a review before the deadline (which is great!) and says that it is "final", I will not accept changes to it after I receive it.

Progress on NCA History

by Michael Chesnes

Thank you everyone who contacted me with materials and memories from NCA history. I am gathering the notes I have collected so far, and will summarize what I have found at an upcoming meeting. Elizabeth Forbes Wallace and I begun reviewing tapes of the NCA 70th anniversary, which she will copy into a 3 DVD set for us. The tapes are significant for NCA history, and will help her produce a public service announcement to promote NCA. If you are interested in a one-on-one interview for a PSA, please contact me at m.chesnes@verizon.net or (301) 317-0937.



November 2007 Talk by Dr. Joan Centrella
"Binary Black Holes and Gravitational Waves"

(Continued from page 1)

fects of a *circularly* polarized gravitational wave takes longer to describe. See Chapter 13 of the book *Gravitation*, by Misner, Thorne and Wheeler.)

Do gravitational waves really exist?
What evidence is there that gravitational waves actually exist? Dr. Centrella described the remarkable measurements by Hulse and Taylor of the changing period of a pair of mutually orbiting neutron stars, one of which was a pulsar, PSR 1913+16. The pulsar provided a precise way of monitoring the orbital period of the binary. They were able to measure the change in the period over time, and found that it matched the changes that would occur if the pair were losing energy solely by gravitational radiation as calculated by general relativity. In 1993, Hulse and Taylor were awarded the Nobel Prize for this work.

But that evidence is still only indirect. Direct detection of gravitational radiation would be stronger evidence. It would also open up a remarkably powerful new astronomical technique: gravitational wave astronomy. Propagating gravitational waves interact very weakly with matter, so they can reach us through barriers that block other forms of radiation. They will allow us to see farther — hence further back in time — than we can see in any other way. For example, they can penetrate the wall of ionization that preceded the emission of the Cosmic Background Radiation that reaches us today as microwaves, redshifted to a spectrum corresponding to a temperature of 2.7 Kelvins.

Detecting gravitational waves
To detect gravitational waves, we need to know what wave amplitudes, frequencies, and waveforms to expect. That knowledge will be essential for picking out the weak signal produced by the gravitational waves against the background of noise. It will also help us interpret whatever we detect.

The most intense gravitational waves will come from the in-spiraling and merger of pairs of mutually orbiting black holes. Dr. Centrella noted that the central bulges of galaxies harbor super-massive black holes, with masses of a million suns or more. Our own Milky Way and nearby Andromeda are examples. These two galaxies are on a collision course. When such galaxies collide, their central super-massive black holes sometimes go into orbit around each other, setting the stage for an eventual merger. Dr. Centrella showed examples of three systems which exhibit two interacting super-massive black holes: Abell 400, in which the two super-massive black holes are about 25,000 light years apart, NGC 6244, in which they are about 3000 light years apart, and 0402+379, in which they are only 24 light years apart.

The massive black holes at the centers of many, perhaps all, galaxies have masses of 100,000 solar masses or more. For example, the massive black hole at the center of our galaxy, Sagittarius A*, has a mass of about four million solar masses. But there are also other types of black holes. Stellar-mass black holes result from the gravitational collapse of individual massive stars. Their masses range from five solar masses to a few tens of solar masses. The long-sought intermediate-mass black holes may also exist, with masses ranging from a few hundred to a few thousand solar masses. Intermediate-mass black holes may be the source of power for Ultra Luminous X-ray sources (ULXs).

How black holes do it
The in-spiral and merger of two super-massive black holes has three stages: in-spiral, plunge and merger, and ring down.

Stage 1
General relativistic effects are relatively weak during the in-spiral, so for decades we have been able to calculate the gravitational waves emitted during this phase. As the black holes spiral in they go faster and faster. The resulting gravitational waves increase in frequency and amplitude, so that if the waveform had been acoustic instead of gravitational, it would have sounded like a chirp. The in-spiral lasts for about a year.

Stage 2
General relativistic effects dominate during the plunge and merger. The general relativistic effects during this phase are too strong and too complicated for analytical calculations: both black holes are moving, while producing strong, very deformed gravitational fields that affect their subsequent motion. Two event horizons have to merge into one. So the plunge phase must be calculated numerically. The plunge and merger lasts roughly 5 to 20 minutes, the duration being proportional to the initial total mass of the system of merging black holes. We really need to know the waveform produced during this phase, because during this phase the merging system emits the most power. Its luminosity in gravitational waves can be 10^{23} times the luminosity of the Sun in electromagnetic waves. That is greater than the power put out by all of the stars in the visible Universe.

Stage 3
Finally, the new single event horizon must settle down to a size and shape determined solely by the mass and spin of the merged object, all other information about the prior configuration being carried away by gravitational waves. For decades we have also been able to calculate the gravitational radiation from this ring-down phase, which lasts about half an hour. The waveform during this phase is a damped sine wave.

How to calculate the plunge and merger?
So the difficult problem has been to calculate the plunge and merger, and the gravitational waveform produced by them. Until recently, people struggled in vain to do so, and the story of their struggle and eventual success was a major feature of the talk.

The first step is to approximate the system of differential equations by a system of algebraic equations, by working with a grid of discrete points instead of the original 4D space-time continuum. One direction in the grid is nominally the time direction, and three other directions are nominally directions in space. The idea is to mimic slicing the 4D space-time into 3D hypersurfaces, specify the initial conditions on one of the hypersufaces, and then compute how the system evolves from the first hypersurface to later ones.

This brings us face to face with one of the special challenges of calculations in general relativity. In other scientific and engineering areas, the physical meaning

(Continued on page 4)

November 2007 Talk by Dr. Joan Centrella "Binary Black Holes and Gravitational Waves"

(Continued from page 3)

of the coordinates is fixed and known. If one point-like electrical charge is at $x = 3$ on the x-axis and a second charge is at $x = 7$, then the distance between them is 4 units, and that is the distance to be used when calculating the electrostatic force between the two charges. Not so in general relativity, where the physical intervals between space-time points is determined by a set of coefficients that vary over the space-time, and change as massive bodies move about. For example, for a single static non-rotating black hole, one coordinate has the physical interpretation of a radial coordinate for points outside the black hole's event horizon, but acts physically like the time coordinate for points inside the event horizon. The coordinate that acts physically like the time coordinate at points outside the event horizon acts physically like the radial coordinate at points inside the event horizon.

The goal of the calculation is to determine that set of varying coefficients — the "metric" $g_{\mu\nu}$ of the space-time, because the local curvature of the space-time and other observable quantities are determined by it. So the physical interpretation of the sequence of coordinates traced by each of the bodies does not become known until the metric has been solved for.

Earliest simulations

In the earliest simulations, the simulated black hole ate the calculational grid, because it sucks in space-time itself! This is another striking example of the special challenges posed by simulations in general relativity. (Presumably the grid may also be eaten when simulating any theory that includes general relativity, namely, supergravity or string theory/M-theory. But this problem does not occur in any other area of scientific simulation.)

Another complication is that the time-dependent deforming event horizons are properties of the entire space-time, and cannot be determined from the gravitational field at a particular time. To calculate the event horizons the whole time development must be known. So the calculation must make do with approximations to the horizons, called *apparent horizons*.

Thus began the heroic age of numerical relativity. (Having read a couple of books on numerical relativity, I can attest that Dr. Centrella was one of the main players throughout the heroic age.) Many different formulations of the equations of general relativity were tried. It was difficult to obtain initial data that were consistent with the equations of motion. After each numerical instability was tamed, another would rear its head and have to be contained. It didn't help that classical general relativity predicts an infinite singularity at the very core of each black hole. It seemed that it wouldn't ever be possible to simulate even a single orbital revolution before the run terminated prematurely. Even the younger researchers became discouraged, and some declared that numerical relativity had turned out to be impossible.

Feasible!

The first hint that the calculation might actually be feasible came in 2004. Bruegmann *et al.* "punctured" the singularity at the core of each black hole. This amounts to smoothing away the singular behavior within a small region that is entirely inside the apparent horizon. Ideally, the mutilation should be harmless, since no information should propagate out from the event horizon, and the apparent horizon is supposed to be a reasonable approximation to the event horizon. But numerical errors might allow some leakage. Bruegmann *et al.* also used a coordinate system that rotated with the black holes, so that the black holes had fixed angular coordinates, which helped them minimize the accumulation of numerical errors that could trigger numerical instabilities. They were able to keep their calculation running for an entire single orbit.

As an example of the difficulties that had to be overcome in those days, even Bruegmann *et al.* were unable to calculate the gravitational waveform that would be emitted during their hard won single orbit. The wavelength of the emitted gravitational radiation is ten to a hundred times the size of the regions covered by the apparent horizons. Using an adequately fine grid over the whole region would be too expensive computationally. So techniques for adaptive gridding had to be developed.

Now we finally have two methods that allow calculation of the full sequence of inspiral, plunge and merger, and ringdown, without premature termination.

First, Pretorius *et al.* in 2005 developed a method in which small regions around the infinite singularities are excised from the space-time, instead of being smoothed to remove the singularity, as in the method of "punctures". This creates holes in the computed space-time, but the holes are entirely within the apparent horizons around the black holes, so that the effects of the mutilation can largely be prevented from leaking out. As I understand it, this method can be made to work most easily when the two black holes are spinning in a special way, so that neither seems to spin as "seen" by the other, much as the Moon always keeps nearly the same face toward us.

Then, in 2006, two groups independently developed nearly identical techniques that were versatile enough to cover any binary system, but still avoided premature termination of the calculation. One group was Campanelli *et al.* at the University of Texas in Brownsville, and the other was Baker *et al.* and the group that Dr. Centrella heads at Goddard. Both modified the method of punctures by developing novel but simple techniques of slicing and special systems of coordinates that allowed the punctures to move freely relative to the computational grid.

(Both excisions and punctures mutilate a small region around each infinite singularity. Excision removes the small region, while puncturing retains the region but smoothes it so that it is no longer a singularity. In both cases the mutilation is well inside the apparent horizon, so that ideally no effects of the mutilation should propagate outward. The term "puncture" seems to lend itself to misinterpretation, since the singularity is not removed, it is merely lanced, like a boil.)

This was a breakthrough. Suddenly, what had seemed impossible for so long suddenly became feasible. There was intense excitement, rapid progress, and, soon, intense competition. Equal mass non-spinning pairs of black holes were soon conquered. In contrast to earlier times, when different groups obtained different results even over the completed portions of their runs, now all groups could run through a complete merger, and agreed on the results. Non-spinning black holes with unequal masses were conquered soon after, and then spinning black holes.

November 2007 Talk by Dr. Joan Centrella
"Binary Black Holes and Gravitational Waves"

(Continued from page 4)

Although the calculations are now feasible, they can take two weeks of clock time on a supercomputer. Don't try this at home!

Preparation for exposition

In preparation for showing us the results of the breakthroughs, Dr. Centrella explained the units that would appear on the axes of the subsequent plots of results. Professionals in general relativity find it convenient to use units in which the Newtonian gravitational constant G and the speed of light c are each equal to 1. There is then only one independent dimensional quantity, which is taken to have the dimensionality of mass. It is easy to see how to use these units. The Schwarzschild radius, the radius of the event horizon of a non-rotating black hole of mass M, is $2GM/c^2$. In units where the values of G and c each become 1, the Schwarzschild radius thus becomes $2M$. The Schwarzschild radius of an object having the same mass as the Sun is about 3 km, so the distance corresponding to 1 solar mass is about 1.5 km. The time for light to travel that distance is 1.5 km/c, and since c is close to $3x10^5$ km/sec in ordinary units, that time is 5 microseconds. So the time corresponding to 1 solar mass is 5 microseconds. If a quantity that equals M in the new units is to be interpreted as a distance, the distance in ordinary units is 1.5 km times (M/M_{Sun}), where M_{Sun} is the mass of the Sun. If a quantity that equals M in the new units is to be interpreted as a time, the time in ordinary units is 5 microseconds times (M/M_{Sun}).

The waveform during the merger turns out to look like an sinusoidal oscillation whose amplitude first rises and then falls, much like the picture of a wave packet that is used in textbooks to illustrate the concept of group velocity.

About 3% to 4 % of the initial mass of a pair of equal-mass non-spinning black holes is radiated away as gravitational radiation when they merge. That is a huge amount of energy, compared to any other type of source. About 25% of the initial orbital angular momentum of a pair of equal-mass non-spinning black holes is radiated away as gravitational radiation. The final spin is about 0.7 M. (That is quite large, since 1 M is the maximal spin a black hole can have without having its singularity become exposed to the rest of the Universe.) The full plunge interval takes about 100 M. (The 5 to 20 minute estimated duration of the plunge and merger, given earlier, was obtained by inserting reasonable values of M into this formula, and then converting to ordinary units). Within that time interval, a common event horizon forms at about 18.8 M, according to references cited by Dr. Centrella.

Current focus

A current focus of research in numerical relativity is to calculate the recoil of the merged black hole. Anything that causes the gravitational radiation to be emitted asymmetrically will cause the final black hole to recoil, to conserve momentum. In particular, the merged object will recoil if the black holes had unequal masses before their merger, or were spinning. When non-spinning black holes merge, the recoil velocities are fairly small: 176 km/sec is the maximum, and is attained only when the two masses are equal. (For comparison, the solar wind typically has speeds between 300 and 800 km/sec.). When spinning black holes merge, the recoil velocities are similar but slightly larger, e.g., 250 to 400 km/sec, when the spins of the merging black holes are perpendicular to the orbital plane. But when the spins are not perpendicular to the orbital plane the recoil velocities can be huge, e.g., 2000 or even 4000 km/sec, which are large enough to eject the merged object from its host galaxy.

How to detect

After describing the waveform emitted when black holes merge, Dr. Centrella described the present attempts to detect gravitational waves. For detection, relative changes in length of 10^{21} or less must be reliably distinguished from instrumental fluctuations and from background noise.

Interferometers

Today, most attempts at detection focus on interferometers, rather than on the resonant bars that Joseph Weber tried at the University of Maryland. Since a bar is resonant, it responds only over a very narrow range of frequency, reducing its chances of detecting any particular source. Michelson interferometers are much less frequency-selective, so they have a better chance of detecting gravitational waves.

LIGO, *et al.*

The ground-based interferometric detectors are LIGO, GEO600 and VIRGO. LIGO has two stations, each with two perpendicular 4 km arms. One of the two stations is at Hanford, WA and the other is at at Livingston, LA. LIGO is in operation, but will be upgraded. GEO600 has 600 m arms, and is at Hannover. VIRGO has 3 km arms, and is at Pisa.

LISA

The space-based interferometric detector will be LISA (Laser Interferometric Space Antenna). LISA will consist of three spacecraft at the vertices of an equilateral triangle, following the Earth around its orbit, and lagging about 20 degrees behind the Earth. The interferometer arms are 5 million km long. Laser beams between the three spacecraft will measure the shearing of their mutual separations.

The ground-based and space-based detection systems are complementary. The ground-based systems will detect gravitational waves having frequencies between 10 Hz and 10 kHz. These are relatively high frequencies. Sources emitting gravitational waves in this frequency range include binary systems consisting of two neutron stars, or a neutron star and a stellar-mass black hole, or two stellar-mass black holes. Stellar collapse will also produce signals in this frequency range. In general, this frequency range will allow the detection of signals from low-mass sources. Signals above the detection threshold will be relatively few — after LIGO is improved and becomes LIGO-2, it should see several neutron star-neutron start binaries per year.

LISA will be sensitive to gravitational waves having frequencies between 10-4 and 1 Hz. Weak signals at such low frequencies could not be reliably detected from the ground, because of background noise from traffic and seismic rumbling. The sources in LISA's frequency range have higher mass, and include binary systems of two massive black holes, compact binaries that are not yet close to merger, and the formation of binary systems. There will be a huge number of potentially detectable sources in this frequency range. LISA should detect signals from 10,000 to 30,000 sources in the Milky Way alone, all the time.

If a binary system of two intermediate-mass black holes merge, the in-spiral and

November 2007 Talk by Dr. Joan Centrella
"Binary Black Holes and Gravitational Waves"

(Continued from page 5)

the early part of the merger could be observed by the space-based interferometers, and the later stages could be seen by the ground-based interferometers. Binaries consisting of two white dwarfs would fall in the gap between LIGO and LISA, and be missed.

The antennas are not directional

Gravitational wave antennas are not directional. Especially in the source-rich case, it will be challenging to parse the cacophony into signals from individual sources, and then figure out the directions of each source. It will be difficult, but not impossible. Our ear/brain systems do something similar at a party, using pattern matching. That is why we need to know the shapes of the waveforms. A different approach should work for the 10,000 binaries at any one time that are not yet rapidly spiraling together. Their gravitational waves should be nearly monochromatic, so we will be able to separate them by frequency analysis, analogously to what our car radios do to focus on the signal from a desired radio station. LISA may be able to triangulate a source by monitoring how the arrival time of the waveform varies as the constellation orbits the Sun. If a particular waveform is detected by more than one detector, the times of arrival will give some directional information.

Visualizations of calculations

Near the end of the talk, Dr. Centrella showed a movie of the calculated in-spiral and merger of two spinning black holes. The emerging gravitational radiation had strong circular polarization. An arrow on each black hole indicated its angular momentum. Regardless of the directions of the angular momenta of the two in-spiraling black holes, the angular momentum of the merged black hole was always essentially perpendicular to the orbital plane. This doesn't mean that angular momentum had not been conserved. The jump between the vector sum of the angular momenta of the in-spiraling black holes and that of the merged black hole jump is an artifact of the fact that the huge orbital angular momentum of the pair had not been shown in the movie during their in-spiral. The net spin of the merged system is the vector sum of the huge initial orbital angular momentum and the spins of the two black holes, minus whatever angular momentum had been carried away by the gravitational waves. The final spin is dominated by the initial orbital angular momentum, explaining why it is always nearly perpendicular to the orbital plane.

A talented expositor

Dr. Centrella is a particularly talented expositor. She tamed difficult and highly technical subject matter, making it digestible to a general audience. She used her hands, and props such as the laser pointer, to very vividly illustrate how a pulsar periodically directs a brief pulse of radiation toward us. She used a smooth motion of the laser pointer to guide the audience's attention from THERE to THERE on the slide, so that we could quickly pick out what she wanted us to focus on at the time. That was much more effective than randomly jittering the spot of light over the intended object of attention, as many other speakers do. A crazily moving spot of light leaves the viewer not knowing what he or she is supposed to be looking at, and unable to see it anyway under the dancing bright spot.

Slides on the Web

Dr. Centrella graciously agreed to allow the slides from her talk to be posted on a web site. Once the slides have been posted, the URL will be published in Star Dust.

A few supplemental comments

1 - Don't confuse gravitational waves with the "gravity waves" that arise on a water surface, or within the ocean or atmosphere. Examples of gravity waves are the large surface waves seen on the ocean and on lakes, and the internal buoyancy waves that occur within the volume of the ocean or atmosphere. Gravity waves are really buoyancy waves, since buoyancy provides the restoring force. The potential for confusion is high, because non-professionals often use "gravity waves" as if it were a concise synonym for "gravitational waves."

2 - The actions of polarized gravitational waves differ from those of polarized light waves because gravity is associated with a second rank symmetric tensor field, while light is associated with a first rank tensor field, i.e., with a vector field. That is why each of the two linear polarizations of light causes changes in a single direction perpendicular to the direction of propagation, and the actions for the two different linear polarizations are at right angles to each other, whereas for a linearly polarized gravitational wave each linear polarization causes simultaneous changes in two mutually perpendicular directions that are perpendicular to the direction of propagation, and the pairs of the directions of the changes for the two different polarizations are at 45 degrees to each other. Both light quanta and gravitational quanta are massless; but light quanta have spin 1, while gravitational quanta have spin 2. The spin of any massless quantum can only point either maximally along or maximally opposite to its momentum vector (which is its direction of propagation), since these are the only states that have the same character for all inertial observers, no matter what their velocity. That is why there are only two polarizations even when the spin exceeds 1/2. In going from a light wave to a gravitational wave, the component of spin along the direction of motion doubles, becoming ± 2 instead of ± 1. The angular wave function will then have twice as many peaks and troughs. That is the quantum-mechanical way of saying what had been said above in the language of tensors, namely, that a linearly polarized gravitational wave causes changes along two rather than along one direction perpendicular to the direction of propagation, and that changing from one linear polarization changes the directions of the action by 45 degrees rather than by 90 degrees.

3 – The final size and shape of the event horizon of a black hole is really determined by its mass, spin, and charge, not just by its mass and spin. But any net charge quickly generates large forces that usually cause it to be neutralized, so it is usually assumed that the net charge on a black hole is negligible. That is why the main text simplified the discussion by referring only to mass and spin.

Mid-Atlantic Occultations and Expeditions

by Dr. David Dunham

Asteroidal Occultations

2008 Date	Day	EST	Star	Mag	Planet or Asteroid	dmag	dur. s	Ap. in.	Location
Feb 8	Fri	21:29	2UC34419143	11.9	Goldschmidt	3.5	8	6	NY,ePA,neMD,DE
Feb 8	Fri	23:50	2UC35719150	13.0	Aspasia	0.3	30	11	NJ,nMD,PA,nOH
Feb 9	Sat	20:54	2UC41013641	13.1	Dynamene	0.4	17	11	DE,sMD,VA,wNC
Feb 10	Sun	4:44	2UC37355074	11.4	Cohnia	2.9	6	7	s&wNC,eTN,wKY
Feb 10	Sun	23:29	TYC19130670	11.3	Varuna	8.9	43	7	TNO Americas?
Feb 11	Mon	18:47	PPM 120468	10.4	Eliane	5.8	3	5	NC,VA,MD,PA,NY
Feb 15	Fri	3:38	SAO 79420	9.8	Barolo	6.4	2	4	VA,WV,sOhio
Feb 19	Tue	6:02	TYC68130785	11.4	2001 KC77	11.0	11	7	TNO Americas?
Feb 21	Thu	21:48	2UC35885363	11.4	Kolga	2.8	13	8	WV,wMD,PA,NY
Feb 23	Sat	19:23	HIP 53597	10.8	Frigga	1.6	6	7	sVA,nNC
Feb 25	Mon	20:20	2UC32814084	12.9	Hildrun	3.1	3	10	WV,wMD,sePA,NJ
Feb 27	Wed	5:06	2UC16393921	12.5	Palma	1.0	15	10	wNC,wVA,wMD,PA
Feb 28	Thu	1:30	2UC32204807	13.0	2002 CC249	9.6	6	10	TNO N.Amer.
Mar 8	Sat	23:42	TYC60840700	11.2	Maria	1.9	4	6	sNJ,DE,sPA,nOH
Mar 8	Sat	23:57	PPM 95551	9.8	Kuma	7.6	2	4	NJ,nePA,wNY,ON

Lunar Grazing Occultations

DATE	Day	EST	Star	Mag	%	alt	CA	Location
Feb 10	Sun	21:33	51 Piscium	5.8	17+	14	1S	Salisbury & Sims,NC; double
Feb 13	Wed	18:59	ZC 470	6.8	47+	68	4S	Westminster, MD & Phily, PA
Feb 19	Tue	1:32	SAO 80278	7.5	96+	51	14N	Winchestr,NewBalt,Stafford,VA
Feb 20	Wed	23:56	SAO 99036	8.8	1E	55	48U	s.Erie, Narvon,& W.Chester,PA
Feb 29	Fri	2:56	SAO 184574	8.1	48-	9	10S	W.Chester,PA & Somers Pt., NJ
Mar 3	Mon	5:24	SAO 188263	7.7	20-	9	4S	Oxford, PA & Millville, NJ

Total Lunar Occultations

DATE	Day	EST	Ph	Star	Mag	%	alt	CA	Sp.	Notes
Feb 9	Sat	19:11	D	ZC 3489	7.4	9+	16	87N	K3	mag2 10, sep 3", PA 166
Feb 10	Sun	20:13	D	51 Piscium	5.8	17+	17	38S	B9	ZC68;mag2 8,".2;NCgraze
Feb 15	Fri	19:08	D	ZC 797	6.4	71+	76	51N	B9	maybe close double
Feb 16	Sat	2:19	D	ZC 840	6.3	73+	14	41N	K0	Az 295; spec. binary
Feb 16	Sat	21:20	D	ZC 994	6.6	81+	76	36S	K0	maybe close double
Feb 18	Mon	1:16	D	ZC 1155	6.4	90+	45	32N	F0	PA & NJ graze
Feb 18	Mon	1:40	D	ZC 1157	6.2	90+	41	48N	A2	
Feb 18	Mon	19:56	D	ZC 1269	6.9	95+	50	74N	G5	
Feb 18	Mon	23:06	D	eta Cancri	5.3	95+	71	62S	K3	
Feb 19	Tue	3:09	D	BT Cancri	6.7	96+	32	56N	F0	ZC 1292; small amp.var.
Feb 19	Tue	3:16	D	ZC 1293	6.8	96+	31	78S	K0	Stars in Praesepe
Feb 19	Tue	3:29	D	ZC 1298	6.4	96+	31	78S	K0	
Feb 19	Tue	3:31	D	epsilonCnc	6.3	96+	28	86N	A	ZC 1299
Feb 19	Tue	3:41	D	ZC 1297	6.8	96+	26	53S	A9	maybe close double
Feb 19	Tue	3:45	D	EP Cancri	6.8	96+	25	66N	A6	ZC 1303; small amp.var.
Feb 19	Tue	3:47	D	ZC 1302	6.8	96+	25	30N	A9	spectroscopic binary
Feb 20	Wed	22:23	D	X015418	9.9	0E	51	77U	G0	
Feb 20	Wed	22:40	D	X117743	9.8	0E	53	45U		companion of SAO 99036
Feb 20	Wed	22:40	D	SAO 99036	8.8	0E	53	45U	A0	Prev.+26s;WA41;PAgraze
Feb 20	Wed	23:11	D	SAO 99036	8.8	17E	57	52U	A0	WA 354 deg.
Feb 20	Wed	23:12	D	X117743	9.8	18E	57	52U		SAO 99036 comp.; WA 353
Feb 28	Thu	3:18	R	ZC 2261	6.6	57-	18	66S	K3	
Feb 28	Thu	4:11	R	SAO 183872	7.2	56-	22	37S	F0	
Mar 1	Sat	4:46	R	V2382 Oph	7.2	37-	14	59S	B2	ZC 2540; Az. 148 deg.
Mar 9	Sun	19:52	D	ZC 163	7.3	7+	9	60N	F2	Az278;mg2 10.6 8",PA200

Explanations & more information is at http://iota.jhuapl.edu/exped.htm .

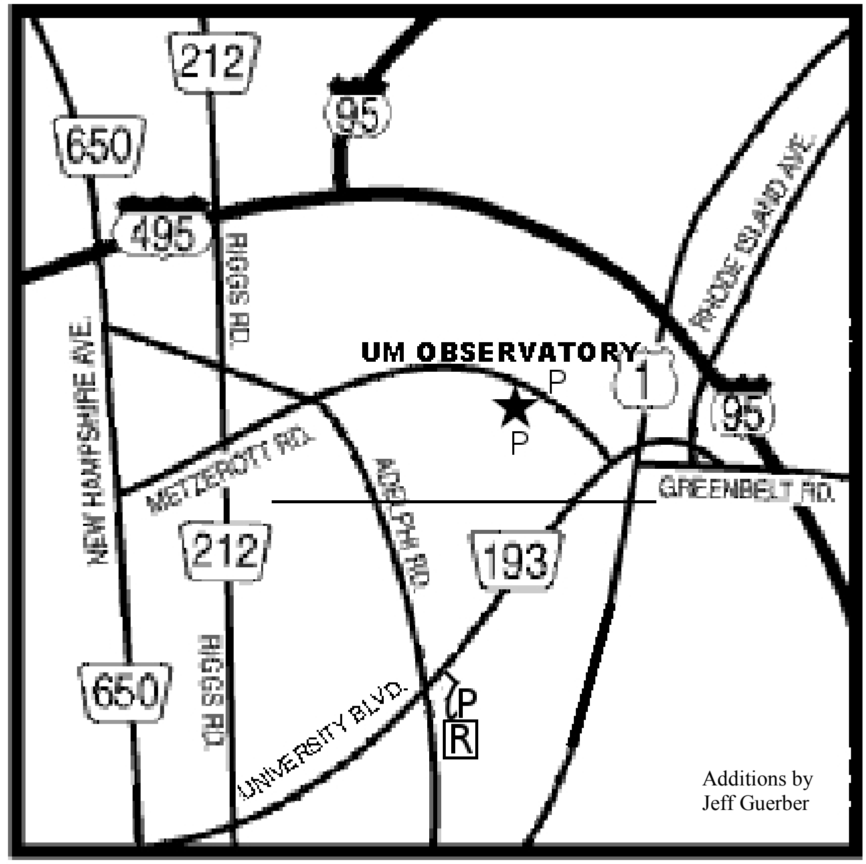
David Dunham, dunham@starpower.net, phone 301-474-4722

Getting to the NCA Monthly Meeting and the Dinner Before the Meeting

The NCA Meeting
NCA meetings are now held at 7:30 p.m. at the University of Maryland Observatory, in College Park. The observatory is located on Metzerott Road between Adelphi Road and University Blvd. in College Park. From the beltway (I-495):

• if on the Inner Loop, take Exit 28B toward Takoma Park, which puts you on New Hampshire Ave. (MD-650) south, turn left at the second light onto Adelphi Road, two more lights, turn left onto Metzerott Road, and proceed 0.6 miles to the observatory entrance (on your right);

• if on the Outer Loop, take the College Park/Route 1 exit. Head south on Route 1 for about a mile until you see a sign for 193 West. Get on 193 West. The first traffic light is at Metzerott Road. Take a right onto Metzerott Road. Once on Metzerott Rd., continue past a traffic light at St. Andrews Place. The observatory entrance is about a quarter of a mile on the left side of the road after that. The observatory entrance is slightly hidden, so slow down to turn left as soon as you pass a large "System Administration" sign. The observatory entrance is almost directly across the street from the UM System Administration sign (3300 Metzerott Rd.).



Getting to the NCA Meeting
Star=Observatory R=Restaurant P=Parking

The Dinner before the Meeting
At 5:30 p.m., before the meeting, please join us for dinner at the Garden Restaurant in the UMD University College Inn and Conference Center, 3501 University Blvd. East at Adelphi Rd. From the Beltway, either take New Hampshire Ave. south, turn left at the second traffic light onto Adelphi Rd., and at the third light (passing Metzerott) turn left onto University then immediately right into the garage; or, take US-1 south, turn right onto University Blvd. west, and take it to the intersection with Adelphi Road. Park either in the garage (costs), or in Lot 1 nearby (free). To get to the observatory, exit to the right onto University Blvd. (MD-193) east, and at the second light turn left onto Metzerott Road. Once on Metzerott Rd., continue past a traffic light at St. Andrews Place. The observatory entrance is about a quarter of a mile on the left side of the road after that. The observatory entrance is slightly hidden, so slow down to turn left as soon as you pass a large "System Administration" sign. The observatory entrance is almost directly across the street from the UM System Administration Sign (3300 Metzerott Rd.).

Do You Need a Ride?

Please contact Jay Miller, 240-401-8693, if you need a ride from the metro to dinner or to the meeting at the observatory. (Please try to let him know in advance by e-mail at rigel1@starpower.net.)

Observing after the Meeting

Elizabeth Warner

Following the meeting, members and guests are welcome to tour through the Observatory. Weather permitting, several of the telescopes will also be set up for viewing.

Star Dust is published ten times yearly, September through June, by the National Capital Astronomers, Inc. (NCA).
Editor: Elliott Fein; Co-editor: Adele Fein; Editorial Advisors: Walt Faust, John D. Gaffey, Jr, Jeffrey Norman, Wayne Warren, Harold Williams; PDF distributor: Jay Miller

National Capital Astronomers, Inc.

http://capitalastronomers.org

SERVING SCIENCE & SOCIETY SINCE 1937

NCA is a nonprofit, membership-supported, volunteer-run, public-service corporation dedicated to advancing astronomy, space technology, and related sciences through information, participation, and inspiration, via research, lectures, presentations, publications, expeditions, tours, public interpretation, and education. NCA is the astronomy affiliate of the Washington Academy of Sciences. NCA is an IRS Section 501(c)(3) tax-deductible organization. All are welcome to join NCA.

SERVICES & ACTIVITIES:

Monthly Meetings feature presentations of current work by researchers at the horizons of their fields. All are welcome; there is no charge.

NCA Volunteers serve in a number of capacities. Many members serve as teachers, clinicians, and science fair judges. Some members observe total or graze occultations of stars occulted by the Moon or asteroids.

Publications received by members include the monthly newsletter of NCA, *Star Dust*, and an optional discount subscription to *Sky & Telescope* magazine.

Consumer Clinics: Some members serve as clinicians and provide advice for the selection, use, and care of binoculars and telescopes and their accessories. One such clinic is the semiannual event held at the Smithsonian Institution National Air and Space Museum.

Fighting Light Pollution: NCA is concerned about light pollution and is interested in the technology for reducing or eliminating it. To that purpose, NCA is an Organization Member of the International Dark Sky Association (IDA).

Classes: Some NCA members are available for educational programs for schools and other organizations. The instruction settings include star parties, classroom instruction, and schoolteacher training programs that provide techniques for teaching astronomy. NCA sponsors a telescope-making class, which is described in the *Star Dust* "Calendar of Monthly Events."

Tours: On several occasions, NCA has sponsored tours of astronomical interest, mainly to observatories (such as the National Radio Astronomy Observatory) and to the solar eclipses of 1998 and 1999.

Discounts are available to members on many publications, products, and services, including *Sky & Telescope* magazine.

Public Sky Viewing Programs are offered jointly with the National Park Service, and others. Contact: Joe Morris, j.c.morris@verizon.net or (703) 620-0996.

Members-Only Viewing Programs periodically, at a dark-sky site.

NCA Juniors Program fosters children's and young adults' interest in astronomy, space technology, and related sciences through discounted memberships, mentoring from dedicated members, and NCA's annual Science Fair Awards.

✂

Yes, I'd like to join NATIONAL CAPITAL ASTRONOMERS!

Name: ____ Date: ____/____/_____
Street address: ____
City/State/ZIP: ____
Telephone: ____-____-______ E-mail: ______________________________
Other family members who should receive a membership card: ______________________
Would you prefer to get *Star Dust* by e-mail? ____

MEMBERSHIP CATEGORIES AND ANNUAL DUES RATES

All members receive Star Dust*, the monthly newsletter announcing NCA activities. As an added optional benefit to extend your knowledge of astronomy, you may also choose* Sky and Telescope *magazine at the discounted rate of $33.*

Student Membership: ………………………………….…. $5 ……………..with *Sky and Telescope*....$38
Standard Individual or Family Membership: ….………..…. $10 ………..…..with *Sky and Telescope*....$43

You are welcome to make contributions in any amount in addition to the dues shown above.
Contribution amount:_________________________

Please mail this form with your check payable to National Capital Astronomers, to:
Mr. Michael L. Brabanski, NCA Treasurer; 10610 Bucknell Drive, Silver Spring, MD 20902-4254

National Capital Astronomers, Inc.
If undeliverable, return to
NCA c/o Michael L. Brabanski
10610 Bucknell Dr.
Silver Spring, MD 20902-4254

FIRST CLASS
DATED MATERIAL

NCA Will Meet on February 8!

Inside this issue: