COMING EVENTS

Public Talks
Kansas Room, Kansas Union
Friday, April 14 7PM
Hubble’s Legacy
Dr. Daniel McIntosh, UMKC

Baker Wetlands Discovery Center-Family Fun Day
Saturday April 15 9 AM -Noon

AAL Meeting
Baker Wetlands Discovery Center
SUNDAY, APR. 30, 7:00 PM
PUBLIC OBSERVING
8:30PM

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The Celestial Mechanic
The Official Newsletter of the Astronomy Associates of Lawrence

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Report from the Officers

Thanks to the ongoing rain of the last few days, the “March” observing session went by the wayside this weekend. We will try again at the end of April. The monthly meeting focused on a busy schedule of events over the next 30 days, a number of which could use some help from club members. As noted on pg. 5, KU will host the 2nd of two public talks tied to astronomical topics, The Legacy of the Hubble Space Telescope by Prof. Dan McIntosh of UMKC. This presentation takes place in the Kansas Union, not the Lawrence Public Library, on Friday evening, April 14. Dan is an excellent speaker and has contributed significantly to the development of the astronomy group at UMKC over the last 9 years. The next day, Saturday April 15, will be the Baker Wetlands Discovery Center Family Fun Day from 9 AM until noon. Weather permitting, AAL is hoping to have the telescope open to allow the visitors to see the observatory and to have some solar observing on display. These will help advertise the club and the public observing sessions each month.

On Saturday, April 22, there will be an Earth Day Celebration at South Park which will include Solar Eclipse Awareness to promote and educate about the August 21st event. The club will be on site to help explain what will happen and, again, hopefully educate the public about the eclipse and amateur astronomy in general.

(Continued on page 2)
About the Astronomy Associates of Lawrence

The club is open to all people interested in sharing their love for astronomy. Beginning in Fall 2016, monthly meetings are typically on the last Sunday of each month and often feature guest speakers, presentations by club members, and a chance to exchange amateur astronomy tips. These meetings and the public observing sessions that follow are scheduled at the Baker Wetlands Discovery Center, south of Lawrence. All events and meetings are free and open to the public. Periodic star parties are scheduled as well. For more information, please contact the club officers: president, Rick Heschmeyer at rcjbm@sbcglobal.net; faculty advisor, Prof. Bruce Twarog at btwarog@ku.edu. Because of the flexibility of the schedule due to holidays and alternate events, it is always best to check the Web site for the exact Sundays when events are scheduled. The information about AAL can be found at

http://www.physics.ku.edu/AAL/

Copies of the Celestial Mechanic can also be found on the web at

http://www.physics.ku.edu/AAL/newsletter
Ancient Stardust Sheds Light on the First Stars

An international team of astronomers, led by Nicolas Laporte of University College London, have used the Atacama Large Millimeter/submillimeter Array (ALMA) to observe A2744_YD4, the youngest and most remote galaxy ever seen by ALMA. They were surprised to find that this youthful galaxy contained an abundance of interstellar dust — dust formed by the deaths of an earlier generation of stars.

Follow-up observations using the X-shooter instrument on ESO’s Very Large Telescope confirmed the enormous distance to A2744_YD4. The galaxy appears to us as it was when the Universe was only 600 million years old, during the period when the first stars and galaxies were forming.

“Not only is A2744_YD4 the most distant galaxy yet observed by ALMA,” comments Nicolas Laporte, “but the detection of so much dust indicates early supernovae must have already polluted this galaxy.”

Cosmic dust is mainly composed of silicon, carbon and aluminum, in grains as small as a millionth of a centimeter across. The chemical elements in these grains are forged inside stars and are scattered across the cosmos when the stars die, most spectacularly in supernova explosions, the final fate of short-lived, massive stars. Today, this dust is plentiful and is a key building block in the formation of stars, planets and complex molecules; but in the early Universe — before the first generations of stars died out — it was scarce.

The observations of the dusty galaxy A2744_YD4 were made possible because this galaxy lies behind a massive galaxy cluster called Abell 2744. Because of a phenomenon called gravitational lensing, the cluster acted like a giant cosmic “telescope” to magnify the more distant A2744_YD4 by about 1.8 times, allowing the team to peer far back into the early Universe.

The ALMA observations also detected the glowing emission of ionised oxygen from A2744_YD4. This is the most distant, and hence earliest, detection of oxygen in the Universe, surpassing another ALMA result from 2016. The detection of dust in the early Universe provides new information on when the first supernovae exploded and hence the time when the first hot stars bathed the Universe in light. Determining the timing of this “cosmic dawn” is one of the holy grails of modern astronomy, and it can be indirectly probed through the study of early interstellar dust.

The team estimates that A2744_YD4 contained an amount of dust equivalent to 6 million times the mass of our Sun, while the galaxy’s total stellar mass — the mass of all its stars — was 2 billion times the mass of our Sun. The team also measured the rate of star formation in A2744_YD4 and found that stars are forming at a rate of 20 solar masses per year — compared to just one solar mass per year in the Milky Way.

“This rate is not unusual for such a distant galaxy, but it does shed light on how quickly the dust in A2744_YD4 formed,” explains Richard Ellis (ESO and University College London), a co-author of the study. “Remarkably, the required time is only about 200 million years — so we are witnessing this galaxy shortly after its formation.”

This means that significant star formation began approximately 200 million years before the epoch at which the galaxy is being observed. This provides a great opportunity for ALMA to help study the era when the first stars and galaxies “switched on” — the earliest epoch yet probed. Our Sun, our planet and our existence are the products — 13 billion years later — of this first generation of stars. By studying their formation, lives and deaths, we are exploring our origins.

“With ALMA, the prospects for performing deeper and more extensive observations of similar galaxies at these early times are very promising,” says Ellis. And Laporte concludes: “Further measurements of this kind offer the exciting prospect of tracing early star formation and the creation of the heavier chemical elements even further back into the early Universe.”
With seven Earth-sized planets that could harbor liquid water on their rocky, solid surfaces, the TRAPPIST-1 planetary system might feel familiar. Yet the system, recently studied by NASA’s Spitzer Space Telescope, is unmistakably alien: compact enough to fit inside Mercury’s orbit, and surrounds an ultra-cool dwarf star—not much bigger than Jupiter and much cooler than the sun.

If you stood on one of these worlds, the sky overhead would look quite different from our own. Depending on which planet you’re on, the star would appear several times bigger than the sun. You would feel its warmth, but because it shines stronger in the infrared, it would appear disproportionately dim.

“It would be a sort of an orangish-salmon color—basically close to the color of a low-wattage light bulb,” says Robert Hurt, a visualization scientist for Caltech/IPAC, a NASA partner. Due to the lack of blue light from the star, the sky would be bathed in a pastel, orange hue.

But that’s only if you’re on the light side of the planet. Because the worlds are so close to their star, they’re tidally locked so that the same side faces the star at all times, like how the Man on the Moon always watches Earth. If you’re on the planet’s dark side, you’d be enveloped in perpetual darkness—maybe a good thing if you’re an avid stargazer.

If you’re on some of the farther planets, though, the dark side might be too cold to survive. But on some of the inner planets, the dark side may be the only comfortable place, as the light side might be inhospitably hot. On any of the middle planets, the light side would offer a dramatic view of the inner planets as crescents, appearing even bigger than the moon on closest approach. The planets only take a few days to orbit TRAPPIST-1, so from most planets, you can enjoy eclipses multiple times a week (they’d be more like transits, though, since they wouldn’t cover the whole star). Looking away from the star on the dark side, you would see the outer-most planets in their full illuminated glory. They would be so close—only a few times the Earth-moon distance—that you could see continents, clouds, and other surface features.

The constellations in the background would appear as if someone had bumped into them, jostling the stars—a perspective skewed by the 40-light-years between TRAPPIST-1 and Earth. Orion's belt is no longer aligned. One of his shoulders is lowered.

And, with the help of binoculars, you might even spot the sun as an inconspicuous yellow star: far, faint, but familiar.

Want to teach kids about exoplanets? Go to the NASA Space Place and see our video called, “Searching for other planets like ours”: https://space-place.nasa.gov/exoplanet-snap/
Hubble’s Legacy: Reflections on the Past, Present, & Future of U.S. Astronomy
Prof. Daniel H. McIntosh
University of Missouri—Kansas City

Friday
April 14, 2017
7:00 p.m.

Kansas Room
Kansas Union
1301 Jayhawk Blvd.
Lawrence, KS 66045

In April 1990, NASA launched the most well-known scientific instrument in history. As an astronomer, educator and U.S. citizen I have reflected on more than 25 years of the Hubble Space Telescope. I will describe the legacies of this great space observatory, illuminate who Edwin Hubble was and why this telescope was named after him, and explain how astronomical science was different in his time compared to today. I will finish by examining the questions "how much did it cost to build the space observatory and was it worth it?". The answers to these questions relate to the future of science in the U.S.

About Professor Daniel H. McIntosh:
Dr. McIntosh is a Distinguished Associate Professor of Astronomy and Astrophysics. Since joining the University of Missouri-Kansas City in August 2008, Prof. McIntosh has established a vibrant astronomy program, founded the UMKC Galaxy Evolution Group, and developed many educational innovations dedicated to actively engaging students from all backgrounds in positive and impactful learning experiences related to science. In 2016, he was awarded the U.Missouri System President’s Award for Innovative Teaching. Dr. McIntosh is also an expert on the physical processes underlying the origins and growth of galaxies - a central feature of cosmic history. Much of his research over the last 16 years has employed data collected by the Hubble Space Telescope.

Public Event
For more information:
785-864-4626
physics@ku.edu
http://physics.ku.edu
Celestial Savings Program—Your Discount Purchasing Program

The Astronomical League is excited to announce its new Celestial Savings Program where all League members qualify for special discounts at participating vendors when purchasing equipment, accessories, or books. Please note that discount amounts may vary by vendor and by items purchased.

If you are a current AL member, you may obtain the discount codes by first logging into your AL member account. If you do not already have an account (your member account is separate from your store account) you may obtain one by visiting https://members.astroleague.org/request_account and entering your email address. An email will be sent to you with instructions describing how to create an account.

Once you have an account established log in to the members website https://members.astroleague.org (the login link is at the upper left of the page); click on “Celestial Savings.” You will then see a listing of the participating vendors, the discounts they offer for their products, their current discount code numbers, their website URLs, and, if appropriate, telephone numbers. Simply provide the appropriate discount code number to the vendor’s salesperson or include it in your website order.

We encourage you to share the existence of the Celestial Savings Program with your astronomy friends, AL members or not. However, please do not share discount codes with anyone.

You’re not an AL member? Contact an AL member astronomy club in your area and join through them. You’ll find AL dues to be very reasonable, and many local clubs pay them for you. The Astronomical League also has a member-at-large program detailed at https://www.astroleague.org/al/general/memblarg.html. For additional AL membership details and benefits, visit www.astroleague.org and click the “Join” tab. Questions? Write to the Celestial Savings director at celestialsavings@astroleague.org.

Milky Way-like galaxies in early universe embedded in 'super halos'

By harnessing the extreme sensitivity of the Atacama Large Millimeter/submillimeter Array (ALMA), astronomers have directly observed a pair of Milky Way-like galaxies seen when the universe was only eight percent of its current age. These progenitors of today’s giant spiral galaxies are surrounded by “super halos” of hydrogen gas that extend many tens-of-thousands of light-years beyond their dusty, star-filled disks. Astronomers initially detected these galaxies by studying the intense light from even-more-distant quasars. As this light travels through an intervening galaxy on its way to Earth, it can pick up the unique spectral signature from the galaxy’s gas. This technique, however, normally prevents astronomers from seeing the actual light emitted by the galaxy, which is overwhelmed by the much brighter emission from the background quasar.

"Imagine a tiny firefly next to a high-power search light. That’s what astronomers are up against when it comes to observing these youthful versions of our home galaxy," said Marcel Neeleman a postdoctoral fellow at the University of California, Santa Cruz, and lead author on a paper appearing in the journal Science. "We can now see the galaxies themselves, which gives us an amazing opportunity to learn about the earliest history of our own galaxy and others like it."

With ALMA, the astronomers were finally able to observe the natural millimeter-wavelength "glow" emitted by ionized carbon in the dense and dusty star-forming regions of the galaxies. This carbon signature, however, is consid-

(Continued on page 10)
Gravitational Wave Kicks Monster Black Hole Out Of Galactic Core

Astronomers have uncovered a supermassive black hole that has been propelled out of the center of a distant galaxy by what could be the awesome power of gravitational waves. Though there have been several other suspected, similarly booted black holes elsewhere, none has been confirmed so far. Astronomers think this object, detected by NASA's Hubble Space Telescope, is a very strong case. Weighing more than 1 billion suns, the rogue black hole is the most massive black hole ever detected to have been kicked out of its central home.

Researchers estimate that it took the equivalent energy of 100 million supernovas exploding simultaneously to jettison the black hole. The most plausible explanation for this propulsive energy is that the monster object was given a kick by gravitational waves unleashed by the merger of two hefty black holes at the center of the host galaxy.

First predicted by Albert Einstein, gravitational waves are ripples in space that are created when two massive objects collide. The ripples are similar to the concentric circles produced when a hefty rock is thrown into a pond. Last year, the Laser Interferometer Gravitational-Wave Observatory (LIGO) helped astronomers prove that gravitational waves exist by detecting them emanating from the union of two stellar-mass black holes, which are several times more massive than the sun. Hubble's observations of the wayward black hole surprised the research team. "When I first saw this, I thought we were seeing something very peculiar," said team leader Marco Chiaberge of the Space Telescope Science Institute (STScI) and Johns Hopkins University, in Baltimore, Maryland. "When we combined observations from Hubble, the Chandra X-ray Observatory, and the Sloan Digital Sky Survey, it all pointed towards the same scenario. The amount of data we collected, from X-rays to ultraviolet to near-infrared light, is definitely larger than for any of the other candidate rogue black holes."

Hubble images taken in visible and near-infrared light provided the first clue that the galaxy was unusual. The images revealed a bright quasar, the energetic signature of a black hole, residing far from the galactic core. Black holes cannot be observed directly, but they are the energy source at the heart of quasars — intense, compact gushers of radiation that can outshine an entire galaxy. The dotted line marks the visible periphery of the galaxy. The quasar, named 3C 186, appears as a bright star just off-center. The quasar and its host galaxy reside 8 billion light-years from Earth. Researchers estimate that it took the equivalent energy of 100 million supernovas exploding simultaneously to jettison the black hole. The most plausible explanation for this propulsive energy is that the monster object was given a kick by gravitational waves unleashed by the merger of two hefty black holes at the center of the host galaxy. The Hubble image combines visible and near-infrared light taken by the Wide Field Camera 3.

This image, taken by NASA's Hubble Space Telescope, reveals an unusual sight: a runaway quasar fleeing from its galaxy's central hub. A quasar is the visible, energetic signature of a black hole. Black holes cannot be observed directly, but they are the energy source at the heart of quasars — intense, compact gushers of radiation that can outshine an entire galaxy. The dotted line marks the visible periphery of the galaxy. The quasar, named 3C 186, appears as a bright star just off-center. The quasar and its host galaxy reside 8 billion light-years from Earth. Researchers estimate that it took the equivalent energy of 100 million supernovas exploding simultaneously to jettison the black hole. The most plausible explanation for this propulsive energy is that the monster object was given a kick by gravitational waves unleashed by the merger of two hefty black holes at the center of the host galaxy. The Hubble image combines visible and near-infrared light taken by the Wide Field Camera 3.

"I was anticipating seeing a lot of merging galaxies, and I was expecting to see messy host galaxies around the quasars, but I wasn't really expecting to see a quasar that was clearly offset from the core of a regularly shaped galaxy," Chiaberge recalled. "Black holes reside in the center of galaxies, so it's unusual to see a quasar not in the center."
The team calculated the black hole’s distance from the core by comparing the distribution of starlight in the host galaxy with that of a normal elliptical galaxy from a computer model. The black hole had traveled more than 35,000 light-years from the center, which is more than the distance between the sun and the center of the Milky Way.

Based on spectroscopic observations taken by Hubble and the Sloan survey, the researchers estimated the black hole’s mass and measured the speed of gas trapped near the behemoth object. Spectroscopy divides light into its component colors, which can be used to measure velocities in space. “To our surprise, we discovered that the gas around the black hole was flying away from the galaxy’s center at 4.7 million miles an hour,” said team member Justin Ely of STScI. This measurement is also a gauge of the black hole’s velocity, because the gas is gravitationally locked to the monster object. The astronomers calculated that the black hole is moving so fast it would travel from Earth to the moon in three minutes. That’s fast enough for the black hole to escape the galaxy in 20 million years and roam through the universe forever.

The Hubble image revealed an interesting clue that helped explain the black hole’s wayward location. The host galaxy has faint arc-shaped features called tidal tails, produced by a gravitational tug between two colliding galaxies. This evidence suggests a possible union between the 3C 186 system and another galaxy, each with central, massive black holes that may have eventually merged.

Based on this visible evidence, along with theoretical work, the researchers developed a scenario to describe how the behemoth black hole could be expelled from its central home. According to their theory, two galaxies merge, and their black holes settle into the center of the newly formed elliptical galaxy. As the black holes whirl around each other, gravity waves are flung out like water from a lawn sprinkler. The hefty objects move closer to each other over time as they radiate away gravitational energy. If the two black holes do not have the same mass and rotation rate, they emit gravitational waves more strongly along one direction. When the two black holes collide, they stop producing gravitational waves. The newly merged black hole then recoils in the opposite direction of the strongest gravitational waves and shoots off like a rocket. The researchers are lucky to have caught this unique event because not every black hole merger produces imbalanced gravitational waves that propel a black hole in the opposite direction. “This asymmetry depends on properties such as the mass and the relative orientation of the back holes’ rotation axes before the merger,” said team member Colin Norman of STScI and Johns Hopkins University. “That’s why these objects are so rare.”

An alternative explanation for the offset quasar, although unlikely, proposes that the bright object does not reside within the galaxy. Instead, the quasar is located behind the galaxy, but the Hubble image gives the illusion that it is at the same distance as the galaxy. If this were the case, the researchers should have detected a galaxy in the background hosting the quasar. If the researchers’ interpretation is correct, the observations may provide strong evidence that supermassive black holes can actually merge. Astronomers have evidence of black-hole collisions for stellar-mass black holes, but the process regulating supermassive black holes is more complex and not completely understood. The team hopes to use Hubble again, in combination with the Atacama Large Millimeter/submillimeter Array (ALMA) and other facilities, to more accurately measure the speed of the black hole and its gas disk, which may yield more insight into the nature of this bizarre object.
As British royal families fought the War of the Roses in the 1400s for control of England's throne, a grouping of stars was waging its own contentious skirmish — a star wars far away in the Orion Nebula.

The stars were battling each other in a gravitational tussle, which ended with the system breaking apart and at least three stars being ejected in different directions. The speedy, wayward stars went unnoticed for hundreds of years until, over the past few decades, two of them were spotted in infrared and radio observations, which could penetrate the thick dust in the Orion Nebula.

The observations showed that the two stars were traveling at high speeds in opposite directions from each other. (Continued on page 10)
erably offset from the gas first detected by quasar absorption. This extreme separation indicates that the galaxies' gas content extends well beyond their star-filled disks, suggesting that each galaxy is embedded in a monstrous halo of hydrogen gas.

"We had expected we would see faint emissions right on top of the quasar, and instead we saw strong bright carbon emission from the galaxies at large separations from their background quasars," said J. Xavier Prochaska, professor of astronomy and astrophysics at UC Santa Cruz and coauthor of the paper. The separation from the quasar to the observed galaxy is about 137,000 light-years for one galaxy and about 59,000 light-years for the other.

According to the researchers, the neutral hydrogen gas revealed by its absorption of quasar light is most likely part of a large halo or perhaps an extended disk of gas around the galaxy. "It's not where the star formation is, and to
The new study is a follow-on to previous Hubble observations that placed the age of the bubbles at 2 million years old.

A black hole is a dense, compact region of space with a gravitational field so intense that neither matter nor light can escape. The supermassive black hole at the center of our galaxy has compressed the mass of 4.5 million sun-like stars into a very small region of space.

Material that gets too close to a black hole is caught in its powerful gravity and swirls around the compact powerhouse until it eventually falls in. Some of the matter, however, gets so hot it escapes along the black hole's spin axis, creating an outflow that extends far above and below the plane of a galaxy.

The team's conclusions are based on observations by Hubble's Cosmic Origins Spectrograph (COS), which analyzed ultraviolet light from 47 distant quasars. Quasars are bright cores of distant active galaxies. Imprinted on the quasars' light as it passes through the Milky Way bubble is information about the speed, composition, and temperature of the gas inside the expanding bubble.

The COS observations measured the temperature of the gas in the bubble at approximately 17,700 degrees Fahrenheit. Even at those sizzling temperatures, this gas is much cooler than most of the super-hot gas in the outflow, which is 18 million degrees Fahrenheit, seen in gamma rays. The cooler gas seen by COS could be interstellar gas from our galaxy's disk that is being swept up and entrained into the super-hot outflow. COS also identified silicon and carbon as two of the elements being swept up in the gaseous cloud. These common elements are found in most galaxies and represent the fossil remnants of stellar evolution.

The cool gas is racing through the bubble at 2 million miles per hour. By mapping the motion of the gas throughout the structure, the astronomers estimated that the minimum mass of the entrained cool gas in both bubbles is equivalent to 2 million suns. The edge of the northern bubble extends 23,000 light-years above the galaxy.

"We have traced the outflows of other galaxies, but we have never been able to actually map the motion of the gas," Bordoloi said. "The only reason we could do it here is because we are inside the Milky Way. This vantage point gives us a front-row seat to map out the kinematic structure of the Milky Way outflow."

The new COS observations build and expand on the findings of a 2015 Hubble study by the same team, in which astronomers analyzed the light from one quasar that pierced the base of the bubble.

"The Hubble data open a whole new window on the Fermi Bubbles," said study co-author Andrew Fox of the Space Telescope Science Institute in Baltimore, Maryland. "Before, we knew how big they were and how much radiation they emitted; now we know how fast they are moving and which chemical elements they contain. That's an important step forward."

The Hubble study also provides an independent verification of the bubbles and their origin, as detected by X-ray and gamma-ray observations.

"This observation would be almost impossible to do from the ground because you need ultraviolet spectroscopy to detect the fingerprints of these elements, which can only be done from space," Bordoloi said. "Only with COS do you have the wavelength coverage, the sensitivity, and the spectral resolution coverage to make this observation."

(Continued from page 12)

see so much gas that far from the star-forming region means there is a large amount of neutral hydrogen around the galaxy," Neeleman said.

The new ALMA data show that these young galaxies are already rotating, which is one of the hallmarks of the massive spiral galaxies we see in the universe today. The ALMA observations further reveal that both galaxies are forming stars at moderately high rates: more than 100 solar masses per year in one galaxy and about 25 solar masses per year in the other.

"These galaxies appear to be massive, dusty, and rapidly star-forming systems, with large, extended layers of gas," Prochaska said.

"ALMA has solved a decades-old question on galaxy formation," said Chris Carilli, an astronomer with the National Radio Astronomy Observatory in Socorro, N.M., and co-author on the paper. "We now know that at least some very early galaxies have halos that are much more extended that previously considered, which may represent the future material for galaxy growth." The galaxies, which are officially designated ALMA J081740.86+135138.2 and ALMA J120110.26+211756.2, are each about 12 billion light-years from Earth. The background quasars are each roughly 12.5 billion light-years from Earth.
Hubble Dates Black Hole’s Last Big Meal

For the supermassive black hole at the center of our Milky Way galaxy, it’s been a long time between dinners. NASA’s Hubble Space Telescope has found that the black hole ate its last big meal about 6 million years ago, when it consumed a large clump of infalling gas. After the meal, the engorged black hole burped out a colossal bubble of gas weighing the equivalent of millions of suns, which now billows above and below our galaxy’s center.

The immense structures, dubbed the Fermi Bubbles, were first discovered in 2010 by NASA’s Fermi Gamma-ray Space Telescope. But recent Hubble observations of the northern bubble have helped astronomers determine a more accurate age for the bubbles and how they came to be.

“For the first time, we have traced the motion of cool gas throughout one of the bubbles, which allowed us to map the velocity of the gas and calculate when the bubbles formed,” said lead researcher Rongmon Bordoloi of the Massachusetts Institute of Technology in Cambridge. “What we find is that a very strong, energetic event happened 6 million to 9 million years ago. It may have been a cloud of gas flowing into the black hole, which fired off jets of matter, forming the twin lobes of hot gas seen in X-ray and gamma-ray observations. Ever since then, the..."