OSS/SEU GPRA Metrics for FY03

NASA Self-Assessment: Alan Smale, May 29, 2003
SEUS Modification and Concurrence: {insert name, date}

1. Identify dark matter and learn how it shapes galaxies and systems of galaxies:
   GREEN

2. Determine the size, shape, age, and energy content of the Universe:
   BLUE

3. Discover the sources of gamma-ray bursts and high energy cosmic rays:
   GREEN

4. Test the general theory of relativity near black holes and in the early Universe, and search for new physical laws using the universe as a laboratory:
   GREEN

5. Reveal the nature of cosmic jets and relativistic flows:
   GREEN

1. Identify dark matter and learn how it shapes galaxies and systems of galaxies

- Combining data from NASA's Far Ultraviolet Spectroscopic Explorer (FUSE) and Chandra X-ray Observatory satellites, astronomers have found evidence for the existence of a large reservoir of baryons in our Local Group of galaxies. This baryonic matter forms a 'warm fog' surrounding and enveloping the Milky Way and its neighbors. The amount of matter discovered, around 10^12 solar masses, is in good agreement with the amount required to gravitationally bind together the galaxies within the Local Group. [http://universe.nasa.gov/press/2003/030219a.html & Nicastro et al, 2003, Nature, 421, 719]

- New evidence from NASA's Chandra X-ray Observatory has challenged an alternative theory of gravity that eliminates the need for dark matter. An observation of the galaxy NGC 720 has shown that it is enveloped in an ellipsoidal cloud of hot gas. The shape and orientation of this hot gas cloud require it to be confined by a dark matter halo, and match the predictions of theories of cold dark matter. The alternative theory, known as MOND (Modified Newtonian Dynamics), cannot explain the results of the Chandra observation. This is the first dynamical evidence that successfully distinguishes dark matter from MOND. [Buote et al, 2002, ApJ 577, 183 & http://universe.gsfc.nasa.gov/press/2002/021022a.html]

- Using the deepest visible-light images ever taken in space, astronomers using NASA's Hubble Space Telescope have reliably measured the age of the spherical

halo of stars surrounding our neighboring Andromeda galaxy, M31. To their surprise, they discovered that about a third of the stars in Andromeda's halo formed only 6 to 8 billion years ago, differing greatly from the 11-to-13 billion year age of the stars in the Milky Way's halo. Also, these young stars in Andromeda are unusually rich in heavy elements. Although a near twin to our Milky Way in many respects, the Andromeda galaxy clearly has a slightly different upbringing, perhaps due to a merger with another large galaxy, or a series of mergers with smaller galaxies, billions of years ago. [NASA Press Release 03-160: http://www.nasa.gov/home/hqnews/2003/may/HQ_news_03160.html]

- NASA's Galaxy Evolution Explorer (GALEX), a small Explorer class mission, was successfully launched on Apr 28th 2003. This orbiting telescope will observe a million galaxies in ultraviolet light, across 10 billion years of cosmic history, providing data that will allow scientists to determine how galaxies evolve. Additionally, GALEX will probe the causes of star formation during a period when most of the stars and elements we see today had their origins. [NASA Press Release 03-148: http://www.nasa.gov/home/hqnews/2003/apr/HP_news_03148.html http://universe.gsfc.nasa.gov/press/2003/030422a.html]

2. Determine the size, shape, age, and energy content of the Universe

- On February 11th, 2003, spectacular images of the infant universe were released from the first year of operation of NASA's Wilkinson Microwave Anisotropy Probe (WMAP). These images represent the most detailed all-sky maps ever obtained of the cosmic microwave background, the afterglow of the big bang. One of the biggest surprises revealed in the data is that the first generation of stars to shine in the universe first ignited only 200 million years after the big bang, much earlier than many scientists expected. In addition, the new portrait precisely pegs the age of the universe at 13.7 billion years old, with a 1% margin of error, and accurately defines the contents of our universe: 4% ordinary matter, 23% of an unknown type of dark matter, and 73% dark energy. The microwave background averages 2.73 degrees above absolute zero; WMAP resolves slight temperature fluctuations that vary by only millionths of a degree. Taken overall, the WMAP results represent a milestone in how we view our universe. [NASA Press Release 03-064: http://www.nasa.gov/home/hqnews/2003/feb/HP_news_03064.html, & http://universe.nasa.gov/press/2003/030211a.html along with substantial media coverage on CNN, in the New York Times, Washington Post, San Francisco Chronicle, Time Magazine, and so on. 13 papers in press at ApJ, including the overview paper: Bennett et al. 2003, astro-ph/0302207]

- Researchers using NASA's Hubble Space Telescope have directly observed faint red young galaxies dating from the conclusion of the cosmological epoch known as the "Dark Ages", a time about a billion years after the Big Bang, when the universe was seven times smaller than it is today, and newly-formed stars and galaxies were just

beginning to become visible. The galaxies, thirty in total, were observed in a small portion of the sky which contains no known nearby bright galaxies; researchers estimate that at least 400 million such objects filled the entire universe at this cosmic epoch. NASA's planned seven meter James Webb Space Telescope is expected to see the entire population of these proto-galactic objects. [NASA Press Release 03-008: ftp://ftp.hq.nasa.gov/pub/pao/pressrel/2003/03-008.txt]

- Scientists using NASA's Chandra X-ray Observatory have taken a snapshot of the adolescent Universe from about 5 billion years ago, when the familiar web-like structure of galaxy chains and voids first emerged. The observation reveals distant and massive galaxies dotting the sky, clustered together under the gravitational attraction of deep, unseen pockets of dark matter. The Chandra observation traced a patch of sky known as the Lockman Hole, and saw a rich collection of active galaxies seven times denser than those detected in previous optical and radio surveys at similar distances. [http://universe.gsfc.nasa.gov/press/2003/030325b.html]

3. <u>Discover the sources of gamma-ray bursts and high-energy cosmic rays</u>

- Following the detection of a gamma-ray burst by NASA's High Energy Transient Explorer satellite, HETE-2, the optical afterglow of the burst was detected just minutes later. The afterglow, with a brightness of 15th magnitude, marked the location of the burst in a host galaxy more than 10 billion light years from the Earth. The gamma-ray burst itself lasted approximately 100 seconds, a relatively bright and long-lasting event. In the days and weeks following the detection of the burst on Oct 4th, 2002, the burst was observed by ~100 telescopes in 11 countries. [NASA Press Release 02-196: ftp://ftp.hq.nasa.gov/pub/pao/pressrel/2002/02-196.txt & http://universe.gsfc.nasa.gov/press/2002/021008a.html] Further analysis of data from the above burst, named GRB021004, revealed the ongoing energizing of the burst afterglow for more than half an hour after the burst. The findings support the collapsar model, where the core of a massive star collapses into a black hole. [http://universe.gsfc.nasa.gov/press/2003/030319a.html & Fox et al, 2003, Nature, 422, 284]

- On Dec 11th 2002, scientists observed a particularly fast-fading type of "dark" gamma-ray burst with NASA's HETE-2 satellite. "Dark" bursts are so named because they have had no detectable optical afterglow – until now. Other bursts have afterglows that linger for days or weeks, likely caused by the explosion's shock waves ramming into and heating gas in the interstellar medium. Activated by the HETE-2 detection, the ground-based RAPTOR automated telescope operated by Los Alamos National Laboratory in New Mexico, observed a rapidly-fading afterglow 65 seconds after the burst. Scientists have thus obtained their most detailed look yet at the rarest type of gamma-ray bursts; if not for HETE-2's rapid dissemination of the position, this afterglow would have been missed. [NASA Press Release 02-257:

ftp://ftp.hq.nasa.gov/pub/pao/pressrel/2002/02-257.txt & http://universe.nasa.gov/press/2002/021223a.html]

- On Saturday March 29th, 2003, NASA's HETE-2 satellite observed one of the brightest and closest gamma-ray bursts ever seen, in the top one percent of all bursts in terms of intrinsic brightness. At its peak the afterglow may have been fleetingly visible to the naked eye; when measured more than one hour after the burst, it was still as bright as a 12th magnitude star. The burst originated approximately two billion light years from Earth, with a redshift of 0.168, making it the second closest burst with a known redshift. Hundreds of professional and amateur astronomers contributed follow-up observations of this spectacular event.
  [http://universe.gsfc.nasa.gov/press/2003/030331b.html] In the week following the burst, astronomers spotted the telltale signs of a supernova in the afterglow, providing convincing evidence that some gamma-ray bursts are directly linked with massive supernova explosions.
  [http://universe.gsfc.nasa.gov/press/2003/030410b.html]

- Scientists used the grating spectrometer aboard NASA's Chandra X-ray Observatory to perform an unusually long observation of the afterglow of GRB020813. The detection of silicon and sulfur ions in the X-ray spectrum provides strong evidence that the burst originated in a supernova-like explosion of an extremely massive star, and that the radiation from the burst was beamed into a narrow cone.
  [http://universe.nasa.gov/press/2003/030324c.html]

- While observing solar flares, NASA's Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) satellite fortuitously observed an extremely bright gamma-ray burst in the background, over the edge of the sun, revealing for the first time that the gamma rays in such a burst are polarized. The high degree of polarization – 80% - is consistent with the maximum possible polarization from electrons spiraling around magnetic field lines, indicating that the gamma-ray burst itself is powered through the generation of a strong, organized magnetic field.
  [Nature, 2003, May 22 issue, and NASA Press Release 03-180:
  http://www.nasa.gov/home/hqnews/2003/may/HQ_03180_Rhessi.html]

- In research supported by NASA and the Hungarian National Research Foundation, and using data amassed using the BATSE instrument on the NASA Compton Gamma Ray Observatory, astronomers have analyzed nearly 2000 gamma-ray bursts and concluded that the two major burst varieties (i.e. those longer than, and shorter than, 2 seconds) show a different physical behavior, with a high degree of statistical certainty. Long bursts originate from explosions of stars more than 30 times more massive than our Sun, whereas short bursts may be black hole or neutron star mergers. [http://universe.nasa.gov/press/2003/030220a.html & Balazs et al 2003, A&A, 401, 129]

4. **Test the general theory of relativity near black holes and in the early Universe, and search for new physical laws using the universe as a laboratory**

- Using data from NASA's Chandra X-ray Observatory, scientists have discovered that two supermassive black holes exist together in the nucleus of the same galaxy, an extraordinarily bright galaxy known as NGC 6240 at a distance of 400 million light-years. The black holes currently orbit one another, and will merge within a few hundred million years to create an even larger black hole, a catastrophic event that will unleash intense radiation and gravitational waves. [NASA Press Release 02-222: ftp://ftp.hq.nasa.gov/pub/pao/pressrel/2002/02-222.txt , http://universe.nasa.gov/press/2002/021119a.html]

- Observations of the supermassive black hole at the center of our Milky Way using NASA's Chandra X-ray Observatory have revealed that the black hole is prone to numerous outbursts. In a set of observations spanning a two-week period the black hole, named Sagitarrius A*, displayed several X-ray flares. The rapidity of these flares indicates that they occur near the black hole's event horizon; the relative weakness of the emission suggests that the black hole, weighing in at 3 million times the mass of the sun, is relatively 'starved' – perhaps indicating that explosive events of the past blew away much of the available gas from its immediate neighborhood. [NASA Press Release 03-002: ftp://ftp.hq.nasa.gov/pub/pao/pressrel/2003/03-002.txt & http://universe.nasa.gov/press/2003/030106a.html]

- NASA's Chandra X-ray Observatory image of the mysterious "Black Widow" pulsar has revealed the first direct evidence of an elongated cocoon of high-energy matter and antimatter particles. This millisecond pulsar, known officially as B1957+20, received its nickname because its intense high-energy radiation is destroying its companion through evaporation. The motion of B1957+20 through the galaxy creates two bow shock waves; the primary shock wave is visible in optical telescopes, the secondary wave, created by pressure that sweeps the wind back from the pulsar to form the high-energy cocoon, is visible for the first time in the Chandra images. The Chandra result confirms the theory that even a relatively weakly magnetized neutron star can generate intense electromagnetic forces and accelerate particles to high energies to create a pulsar wind, if it is rotating rapidly enough. [NASA Press Release 03-081: http://www.nasa.gov/home/hqnews/2003/feb/HP_news_03081.html http://universe.gsfc.nasa.gov/press/2003/030227a.html & Stappers et al 2003, Science, 299, 1372.]

- Using data from NASA's Rossi X-ray Timing Explorer, researchers have identified the most magnetic object known in the Universe: the soft gamma-ray repeater SGR 1806-20, one of ten unusual neutron stars classified as magnetars. The magnetic field strength, some 10^15 Gauss, is ten times more powerful than previously thought (the Sun's average magnetic dipole is, for comparison, 1-5 Gauss). [Ibrahim et al. 2003, ApJ, 584, L17 & http://universe.nasa.gov/press/2002/021104a.html]

- The International Gamma-ray Astrophysics Laboratory (INTEGRAL) was successfully launched on Oct 17, 2002. NASA is contributing to the INTEGRAL mission in several important areas: critical software, calibration expertise, and the provision of an INTEGRAL Data Center and Guest Observer program for US scientists participating in this ESA-led mission. INTEGRAL's primary goals include studies of black hole and neutron star systems, detecting matter-antimatter collisions in the Galactic center, and studying gamma-ray bursts. [http://universe.gsfc.nasa.gov/press/2002/021023a.html] In the first few months of the INTEGRAL mission, four gamma-ray bursts have been captured at the heart of its field of view. [http://universe.gsfc.nasa.gov/press/2003/030324d.html]

5. Reveal the nature of cosmic jets and relativistic flows

- For the first time, astronomers have tracked the life cycle of X-ray jets from a black hole. A series of images from NASA's Chandra X-ray Observatory has revealed the jets traveled at near light speed for several years before slowing down and fading. Astronomers have used Chandra and radio telescopes to observe two opposing jets of high-energy particles emitted following an outburst from the Galactic double-star system XTE J1550-564 that was first detected by NASA's Rossi X-ray Timing Explorer satellite in 1998. At that time the X-ray jets were moving at approximately half the speed of light; four years later, the jets were more than three light years apart, decelerating, and fading. These observations mark the first time that jets have been caught in the act of slowing down. [NASA Press Release 02-189: ftp://ftp.hq.nasa.gov/pub/pao/pressrel/2002/02-189.txt http://universe.gsfc.nasa.gov/press/2002/021003a.html & Corbel, S. et al., 2002, Science, 298, 196 (Oct 4, 2002)]

- NASA's Chandra X-ray Observatory has discovered lobes of unexpectedly hot gas speeding away from a black hole in our galaxy. The high temperature (50 million degrees) and the distance of the lobes from the black hole (0.25 light years) indicate that violent collisions are occurring between clumps of gas expelled from the vicinity of the black hole (in SS433). Scientists had previously predicted that no hot gas would be found further than a few million km from the black hole. [Migliari et al 2002, Science, 297, 1673, & http://universe.nasa.gov/press/2002/021211a.html]

- A long look at the supermassive black hole at the center of our galaxy using NASA's Chandra X-ray Observatory reveals the presence of a pair of X-ray lobes placed symmetrically about Sgr A* at distances of 8.5 pc, possibly collimated ejections from the vicinity of Sgr A*. In addition a number of filamentary X-ray structures, some with radio counterparts, have been found within the extended emission structures. [Morris et al 2002, BAAS 201, 3105, & NASA Press Release 03-002: ftp://ftp.hq.nasa.gov/pub/pao/pressrel/2003/03-002.txt & http://universe.nasa.gov/press/2003/030106a.html]

- Farther afield, images made by Chandra have revealed the mechanisms by which supermassive black holes control the growth of massive galaxies in the distant universe. The X-rays were detected from vast clouds of high-energy particles around the galaxies 3C294 and 4C41.17, respectively 10 and 12 billion light years from Earth. The energetic particles were left over from past explosive events that can be traced through the X-ray and radio jets back to the supermassive black holes in the centers of these galaxies. In each case the galaxy is undergoing an energetic phase in which the giant black hole transfers energy into the surrounding gas. The galaxy and its black hole will continue to grow until the energy generated by jets near the black hole stops the fall of matter into the black hole. When jet activity subsides, matter will resume falling into the black hole, beginning the cycle anew. [Fabian et al., 2003, MNRAS, 341, 729, & NASA Press Release 03-173: http://www.nasa.gov/home/hqnews/2003/may/HQ_news_03173.html]

- NASA scientists using data from the European XMM-Newton observatory and NASA's Rossi X-ray Timing Explorer have obtained new results from an intermediate-mass black hole system in the galaxy M82. Their discovery of quasi-periodic oscillations and a broad iron line feature from this ultra-luminous X-ray source rule out beaming in this system, and indicating the surprising result that the system has a much hotter accretion disk than Galactic stellar black holes. [Strohmayer & Mushotzky, 2003, ApJ, 586, L61, http://universe.gsfc.nasa.gov/press/2003/030324b.html & http://www.gsfc.nasa.gov/news-release/releases/2003/03-33.htm]

- Using data from NASA's Chandra X-ray Observatory and ESA's XMM-Newton satellite, astronomers have found evidence of winds with speeds of 40% the speed of light, blowing away copious amounts of gas from the cores of two quasar galaxies (APM 08279+5255 and PG1115+080) that are believed to be powered by black holes. These winds may also regulate black hole growth and spur the creation of new stars. [http://universe.gsfc.nasa.gov/press/2003/030325a.html]