High-Energy Space Missions Workshop

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Abstract Book

The most luminous blazars and the heaviest black holes

M. Ajello (Clemson University)

Abstract

MeV blazars are a sub-class of jetted AGN, that have larger-than-average jet powers and accretion luminosities. They are thought to harbor the heaviest black holes with masses often in excess of 10 billion solar mass. Because of their relativistic jets, MeV blazars can be detected at high redshift allowing us to study the mass function of heavy black holes in the early Universe and their formation mechanisms. MeV blazars are best studied in the hard X-ray and soft MeV regimes. I will review the scientific aspects that motivate surveys of MeV blazars, what we can learn from them and what are the best strategies and instruments to unveil them.

Development of X-ray Microcalorimeter Imaging Spectrometers
for the X-ray Surveyor Mission Concept

Simon Bandler (NASA Goddard Space Flight Center), Joseph Adams (GSFC), James Chervenak (GSFC), Megan Eckart (GSFC), Fred Finkbeiner (GSFC), Caroline Kilbourne (GSFC), Sang-Jun Lee (GSFC), Richard Kelley (GSFC), Frederic Porter (GSFC), Stephen Smith (GSFC), Thomas Stevenson (GSFC), Edward Wassell (GSFC), Wonsik Yoon (GSFC), Joel Ullom (NIST), Douglas Bennett (NIST), William Doriese (NIST), Gene Hilton (NIST), Benjamin Mates (NIST), Carl Reintsema (NIST), Dan Swetz (NIST), Kent Irwin (Stanford), Alexey Vikhlinin (Smithsonian Astrophysical Observatory).

Abstract

While requirements for instruments on the X-ray Surveyor are still under study, an initial conceptual design includes an X-ray microcalorimeter instrument with a field-of-view of 5'x5' and pixel sizes corresponding to 1”. Thus a nominal array of 300 x 300 pixels (90k pixels) on a 50 μm pitch is required over an area of 1.5 x 1.5 cm. In general, the best energy resolution possible is desirable. However, it is considered acceptable to sacrifice some energy resolution in order to meet the rather challenging pixel number requirements.

We have developed conceptual designs utilizing transition-edge sensor (TES) and magnetically coupled calorimeters (MCC) as the sensors that have the potential to meet these requirements. To reduce the number of sensors read out to a plausible scale, the most promising detector geometries are those in which a thermal sensor such a TES or MCC can read out a sub-array of 20-25 individual 1” pixels. Position discrimination is achieved through the different pulse shapes produced, since each absorber is connected by a different strength thermal connection. This "hydra" geometry is very attractive when the pixel pitch desired is this fine, and thus the combined heat capacity of the entire sub-array is therefore sufficiently small to maintain very high energy resolution. If this scale of "hydra" design is successful, then the number of sensors needed to be read out is the same as is currently proposed for the X-ray Integral Field Unit instrument on ESA's Athena mission (~3840). Therefore the multiplexing technologies currently being developed for Athena could be directly transferable to this spectrometer.

Alternative read-out approaches also exists that utilize microwave SQUIDs coupled to each sensor in resonator circuits in the GHz frequency range. The resonators are spaced closely in frequency, allowing hundreds of resonators to be read out with each amplifier chain. This technology has not yet reached the same level of technical maturity. However, this read-out has the potential for meeting and even exceeding the read-out requirements with just a handful of signal chains. In this presentation I will review the current state-of-the art for the detector and read-out approaches described.

The Future of X-ray Reflection Studies in the 2020s and Beyond

Laura Brenneman (SAO)

Abstract

The so-called "reflection" features in the X-ray spectra of AGN and actively accreting stellar-mass black holes can encode unique information about both the black holes themselves and their surrounding environs. If these features are produced close enough to the event horizon, they can be used to measure the mass and spin of the black hole, the accretion rate, and the rate at which energy is deposited back into the interstellar and intergalactic media through outflows. With sufficient photon statistics and spectral and timing resolution we can probe the precise nature of the accretion flow (e.g., variations in its density, ionization and chemical composition as well as the location of its inner edge), investigate the propagation of and interplay between wind- and jet-type outflows, and even discern whether General Relativity is the correct description for the behavior of matter and energy under such extreme gravity. While substantial progress has been made in this field over the past 15 years with observatories such as Chandra, XMM-Newton, Suzaku, RXTE and NuSTAR, however, much work remains to be done in order to realize the full diagnostic potential of this science. I will summarize the current state-of-the-art in the field, as obtained though deep spectral and timing studies performed with the aforementioned observatories. I will then give an overview of the capabilities provided by planned missions such as Astro-H and Athena in this area of research. Finally, I will discuss the technological developments needed to make critical observational advances in reflection science, and to maximize its potential as a means of decoding the astrophysics of black holes.

The Advanced Pair Telescope (APT) Mission Concept

James H. Buckley (Washington University)

Abstract

The Advanced Pair Telescope (APT) is a mission concept aimed at providing the gamma-ray sensitivity required to probe WIMP dark matter over essentially the entire natural range of annihilation cross-sections and masses. The mission concept is based on the design of the Fermi LAT, and makes use of a very large-area scintillating-fiber pair-conversion telescope to achieve the required order-of-magnitude improvement in geometry factor (Etendue) needed to meet this primary scientific objective. Such an experiment could provide constraints over most of the natural parameter space for a generic WIMP/ thermal relic or, in the event of a detection, could provide the spectral measurements needed to identify the properties of the dark matter particle and determine the halo density profile in nearby Dwarf galaxies. The novel instrument design (dual 3m x 3m trackers with a shared 5 radiation-length calorimeter) would also provide more that 4 times the Fermi effective area, twice the Fermi field-of-view (4.8 str) and a >30% improvement in angular resolution up to a maximum energy of about ~100 GeV. We consider the use of scintillating fibers and new SiPM photodetectors to minimize the number of electronic channels and instrument complexity. Preliminary feasibility studies suggest that such an instrument could meet the weight and volume constraints of planned heavy-lift launch vehicles and fit within a probe-class cost envelop. In addition to the primary DM science objective, the very large instantaneous field-of-view and improved sensitivity would enable a range of secondary science objectives including a large improvement in the number of detected GRBs, better sampled light curves of transients, and higher resolution images of extended GeV sources.

LISA in the Gravitational Wave Decade

John Conklin (University of Florida) for the GWSIG.

Abstract

With the expected first direct detection of gravitational waves in the second half of this decade by Advanced LIGO and pulsar timing arrays, and with the launch of LISA Pathfinder in October of this year, this can arguably be called the decade of gravitational waves. Low frequency gravitational waves in the mHz range, which can only be observed from space, provide the richest science with the highest SNR of any gravitational wave detector. A space-based observatory will improve our understanding of the formation and growth of massive black holes, create a census of compact binary systems in the Milky Way, test general relativity in extreme conditions, and enable searches for new physics. LISA, by far the most mature concept for detecting gravitational waves from space, has consistently ranked as one of the nation's top priority large science missions, including in both of the two most recent astrophysics decadal surveys. In 2013, ESA selected the science theme "The Gravitational Universe" for its third large mission, L3, under the Cosmic Visions Program, with a planned launch date of 2034. NASA is currently planning to join with ESA on the L3 mission as a junior partner. ESA has formed a committee, which includes representatives from the US, to advise the space agency on the scientific and technological approaches for a space based gravitational wave observatory. The leading mission design, Evolved LISA or eLISA, is a slightly de-scoped version of the earlier LISA design. This talk will present the current status of space-based gravitational wave observation and the various activities of the Gravitational Wave Science Interest Group (GWSIG), including technology development, updates to the LISA science case, preparation for the launch of LISA Pathfinder and preparation for the 2020 decadal survey.

Gamma-Ray Burst Observations in the 2020s

Valerie Connaughton (USRA), Michael Briggs (University of Alabama, Huntsville), Julie McEnery (NASA GSFC), Jeremy Perkins (NASA GSFC), Judith Racusin (NASA GSFC), and Colleen Wilson-Hodge (NASA MSFC)

Abstract

Gamma-Ray Bursts (GRBs) serve as probes for cosmology, as beacons for multi-messenger astronomy, and as laboratories for the study of jet physics and particle acceleration in ultra-relativistic environments. With observations over seven decades of energy, the Fermi Gamma-ray Space Telescope has revealed that GRBs exhibit distinct spectral and temporal components that have raised many questions about the energy content of the outflows (baryonic or magnetic), the nature of the highest-energy emission, and its association with either the prompt, impulsive phase of the GRB or with the extended, smooth afterglow phase in which the outflow interacts with surrounding material. Afterglow and host galaxy measurements of GRBs detected by the Swift telescope have probed the farthest reaches of the universe. In the coming years, joint electromagnetic, neutrino, and gravitational wave radiation observations of GRBs are a priority, owing to the ease of identifying the impulsive signal and the promising and consequential predictions of multi-messenger signals from GRBs. As we face the possibility of a decade with no major gamma-ray observatory, much science remains in these three key areas. We summarize key observations that are needed in the 2020s and beyond and the characteristics of instruments designed to make them.

From Astro-H to a Next-Generation Compton Telescope:
Science in the ~100 keV to MeV Energy Range

Paolo Coppi (Yale University)

Abstract

I present an overview of the new hard X-ray/soft gamma-ray science possible with the improved Compton telescopes that should become technologically feasible over the next decade, starting with the planned launch of the Astro-H satellite in early 2016.

The Importance of Broad-Band X-ray All-Sky Monitor Coverage

Robin Corbet, Joel Coley (CRESST/UMBC/NASA GSFC)

Abstract

The high-energy sky is well known for its variability compared to its appearance at other wavelengths. X-ray binaries are striking examples of this, exhibiting both periodic and non-periodic modulation on timescales ranging from milliseconds to decades and longer. Because of this, all-sky monitors have been, and will continue to be, vitally important in high-energy astrophysics - not least because of their ability to detect transient outbursts. However, the properties of sources can vary considerably between "soft" and "hard" bands, and different insights can be gained by studying these regimes both individually and together. We present all-sky monitor results on X-ray binaries with an emphasis on the different types of behaviors exhibited in different X-ray energy bands. We use examples from Swift BAT, RXTE ASM, and MAXI observations.

We strongly advocate the continued operation of high-sensitivity X-ray all-sky monitors over very long periods of time including, in particular, broad energy coverage from ~keV to > 15 keV. All-sky monitors provide both key measurements in their own right, and are vital for maximizing the return from pointed missions. Combining future all-sky monitor results with the existing rich archival data also provides the only way to probe the high-energy sky on extremely long timescales in a way not generally feasible at other wavelengths.

Advancing Soft X-ray Spectroscopy with the Off-Plane Grating Rocket Experiment (OGRE)

Casey T. DeRoo (U. Iowa) Randall L. McEntaffer (U. Iowa) James Tutt (U. Iowa) William W. Zhang (NASA/GSFC) Neil J. Murray (Open U.), Stephen L. O'Dell (NASA/MSFC), Webster Cash (U. Colorado), Andrew Holland Open U.), Tom Peterson (U. Iowa), Ted Schultz (U. Iowa), Kenneth Heitritter (U. Iowa)

Abstract

Achieving the soft X-ray (0.3 – 1.5 keV) science goals of the next decade will require X-ray grating spectrometers with performance capabilities that greatly exceed that of current instruments. Successfully building these future spec- trometers requires maturing supporting technologies to meet new performance thresholds and establishing their flight heritage in a fully integrated system. For this purpose, we are developing the Off-Plane Grating Rocket Experiment (OGRE), a suborbital rocket payload with an off-plane reflection grating spectrograph. OGRE will use single crystal silicon mirrors, blazed off-plane gratings and an electron-multiplying CCD (EM-CCD) camera to achieve spectro- graph performance exceeding that of both the Chandra X-ray Observatory and XMM-Newton. We elaborate on the current status of the supporting technologies, the optical design of the instrument, and the anticipated performance of the instrument.

The High Definition X-ray Imager (HDXI) Instrument on the X-ray Surveyor Mission

Abe Falcone (PSU), Ralph Kraft (SAO), Mark Bautz (MIT), David Burrows (PSU), Almus Kenter (SAO), Stephen Murray (SAO), Zach Prieskorn (PSU), Alexey Vikhlinin (SAO)

Abstract

By utilizing optics that couple fine angular resolution (<0.5 arcsec) with large effective area (~2.3 m^2 at 1keV), the X-ray Surveyor mission would enable exploration within a unique scientific parameter space. One of the primary soft X-ray imaging instruments being baselined for this mission concept is the High Definition X-ray Imager, HDXI. This instrument would achieve this fine angular resolution imaging over a wide field of view (> 22 x 22 arcmin) by using a silicon sensor array with small pixels. Silicon sensors enable large-format/small-pixel devices, radiation tolerant designs, and high quantum efficiency across the entire soft X-ray bandpass. To fully exploit the X-ray Surveyor's large collecting area (~30x Chandra) without X-ray event pile-up, the HDXI will be capable of much faster frame rates than current X-ray imagers. The planned requirements and capabilities of the HDXI will be described.

Searching for keV Dark Matter with X-ray Microcalorimeters:
Sounding Rockets and Beyond!

Enectali Figueroa-Feliciano (Northwestern University)

Abstract

High-resolution X-ray spectrometers onboard suborbital sounding rockets can search for dark matter candidates that produce X-ray lines, such as decaying keV-scale sterile neutrinos. Even with exposure times and effective areas far smaller than XMM and Chandra observations, high-resolution, wide field-of-view observations with sounding rockets have competitive sensitivity to decaying sterile neutrinos. We analyze a subset of the 2011 observation by the XQC instrument, and show that better sensitivity is achievable with future observations of the galactic center region by the Micro-X instrument, providing a definitive test of the sterile neutrino interpretation of the reported 3.56 keV excess from galaxy clusters. We also consider the pros and cons of orbital versions of the same mirror-less concept.

High Resolution Spectroscopic Diagnostics for Future X-ray Missions

Adam R. Foster (Smithsonian Astrophysical Observatory)

Abstract

New mission concepts involve new mission technologies or larger instruments which enable the exploration of new phenomena. There are significant trade offs between increasing the effective area, the sensitivity of the instruments, and the energy resolution, with the exact combination determining the range of physics which is available.

In this work, we present a summary of astrophysical diagnostics available, and the energy resolution required to observe them. This will provide a summary of possible physics avenues for exploration, independent of any currently proposed mission concept. This work is based on data in AtomDB and the XSTAR database, and is therefore principally, though not exclusively aimed at the X-ray regime.

Transient Astrophysics Probe (TAP) Mission Concept

N. Gehrels (GSFC), M. Ajello (Clemson) S. Barthelmy (GSFC), M. Bautz (MIT), E. Berger (Harvard), D. Burrows (PSU), N. Butler (ASU), J. Camp (GSFC), S.B. Cenko (GSFC), D. Chakrabarty (MIT), R. Chevalier (UVa), S. Gezari (UMd), G. Gonzalez (LSU), C. Fryer (LANL), J. Grindlay (Harvard), S. Guirec (UMd), D. H. Hartmann (Clemson), J. Hill (GSFC), V. Kalogera (Northwestern), C. Kouveliotou (GWU), J. Kruk (GSFC), A. Kutyrev (GSFC), H. Moseley (GSFC), C. Miller (UMd), R. Mushotzky (UMd), J. Perkins (GSFC), R. Petre (GSFC), A. Ptak (GSFC), J. Racusin (GSFC), R. Remillard (MIT), M. Rieke (U Arizona), P. Shawhan (UMd), A. J. van der Horst (GWU), R. Willingale (U Leicester)

Abstract

We propose a probe-scale mission designed specifically for time domain astronomy of transient sources with capabilities far exceeding anything flown or planned. The high-energy sky is filled with a rich variety of transient objects flaring on a wide range of timescales. Most of these have not been satisfactorily explored yet and are, therefore, extremely interesting targets of the next decade. These include (1) high-redshift gamma-ray bursts, which are unique probes of the first stars and early Universe conditions, (2) tidal disruption events, which trace the mass function of dormant supermassive black holes via transient accretion, (3) supernova shock breakouts, which herald the final stage of stellar collapse shortly after the moment of core explosion and directly constrain key progenitor properties and (4) binary neutron star mergers creating gravitational wave events together with a yet to be discovered electromagnetic signal. X-ray telescopes with wide-field Lobster optics would cover a steradian of the sky instantaneously and the full sky every 90 minutes with 50 times the sensitivity of current wide-field instruments. A mid-size (~50 cm) optical / NIR telescope would give unprecedented, rapid deep observation capabilities. The observatory would self-trigger and follow-up on a minute time-scale. It would serve as a resource to the community for multiwavelength, rapid-response ToO spectroscopy and imaging. The observatory would detect and obtain GRB redshifts in the $z>10$ frontier at a rate of about one per month. It would observe hundreds of tidal disruption events and supernova shock break-outs per year. Building on the successful Swift legacy, it would perform rapid observations of ~ 1000 ToO targets per year of all types responding to community request. The TAP mission is the future ground-breaking discovery machine for the transient Universe.

An Instrument for Time Domain Astronomy in the X-ray Band

Paul Gorenstein (Harvard-Smithsonian Center for Astrophysics)

Abstract

Interest in time domain astronomy exists in all wavelength bands. For example, we look forward to the operations of large optical facilities such as LSST and large radio facilities such as ALMA. However, the 0.5 to 15 keV X-ray band contains the most dramatic and most wide-ranging manifestations of temporal variability. Times scales range from sub-second to years. We describe a focusing instrument with a very large field of view, good angular resolution, and significant effective area that can study X-ray variability in many objects simultaneously and on multiple time scales. The mass and cost should be compatible with a "probe' class mission comparable to NASA's MIDEX series. By detecting photons from the prolonged X-ray afterglow phase as well as from the active GRB phase it would have more sensitivity for detecting and positioning distant gamma-rays bursts than the Swift BAT. It is likely to find more distant objects than can be found by other means. The instrument is a hybrid consisting of a focusing cylindrical lobster-eye optic in one dimension and a 2D coded mask, which provides the source position and angular resolution in the other dimension. In several respects it is superior to both a 2D lobster-eye telescope and a 2D coded mask of comparable size. It has much more collecting area and bandwidth than the 2D lobster-eye for the study of temporal behavior and spectra. The background is much lower than it would be in a 2D coded mask which is subject to the high level of diffuse cosmic X-ray background plus the contributions of hundreds of discrete X-ray sources. The telescope optic is a uniformly spaced array of commercially available glass flats. The glass is like that of the NuSTAR telescopes but without the necessity of imparting the correct curvature to each reflector substrate. All three of these instrument types would require the same large array of position sensitive detectors to cover the very large field of view.

The Future of Very High Angular Resolution X-Ray Astronomy

Paul Gorenstein (Harvard-Smithsonian Center for Astrophysics)

Abstract

The successor to the Chandra X-Ray Observatory, i.e. "the X-ray Surveyor" in NASA's vocabulary, will aim for much larger effective area and a much larger ratio of effective area to mass but can hope for only modestly better angular resolution given the limitations of grazing incidence reflective optics. Achieving orders of magnitude improvement in angular resolution will require a technology based upon very long focal length, i.e. ~1000 km, diffractive-refractive physical optics acting in X-ray transmission rather than grazing incidence reflection. The angular resolution could be a milliarcsecond or better. The sensitivity will not be better than or even as good as Chandra's sensitivity because the background will be much higher due to the large physical size of the images and the smaller bandwidth. The field of view, while intrinsically high, is very small in practice because of the very long focal length and limitations on the size of the detector. While technical development for the X-ray Surveyor has higher priority study of the diffractive-refractive imager should receive some technical support in the next decade to determine its feasibility. The technical challenges are primarily in mission operations rather than in the construction of the optics or detector. With 1000 km focal length, the optics and detector are aboard separate spacecraft in solar orbit or Sun-Earth L2. Only one S/C, e.g. the optics, can be in a true orbit. The other must be forced to follow with the use of a propulsion system operating continuously to counter a gravity gradient.

The Effects of Orbital Environment on X-ray CCD Performance

Catherine E. Grant, Beverly LaMarr, Eric Miller, Mark Bautz (MIT Kavli Institute for Astrophysics & Space Research)

Abstract

X-ray telescopes, such as NASA's Chandra X-ray Observatory and Japan's Suzaku, have flown in space for several decades, however the effects of this hostile environment on sensitive astrophysics instruments are still not completely documented. Both observatories use CCD cameras for imaging spectroscopy of the X-ray sky. The CCDs themselves are similar in design, being fabricated at MIT's Lincoln Laboratory. We compare the on-orbit performance evolution of the Chandra ACIS and Suzaku XIS, to better understand the effect of the radiation environment in low- and high-Earth orbit. After more than a combined twenty years in space, both instruments have suffered performance degradation due to radiation damage, but comparison must take into consideration the operational differences, such as the presence of charge injection and the warmer focal plane temperature of the XIS. The low-Earth orbit of Suzaku has the advantage of a lower and stable particle background during observations, while the Chandra particle background during observations is higher and subject to variations due to the solar cycle and solar storms. This is in contrast to the rate of radiation damage accumulation, which is about four times higher for Suzaku, even after correcting for operational differences. We present models of the particle environments for both Suzaku and Chandra which can explain the apparent discrepancy. We also extrapolate our experience with Chandra and Suzaku to other environments such as the lower ISS orbit and beyond Earth orbit to L2. While the choice of orbit for future missions is obviously dependent on many factors beyond radiation environment, we hope this study will be useful for better informing that choice.

Transient Spectroscopy Observatory (TSO)

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Abstract

Identification of astrophysical transients, and the study of the astrophysical processes they present, requires prompt imaging and spectroscopy. At optical and nIR wavelengths, broad band photometry is sufficient for initial identification but the underlying physics and the utility of GRBs as probes of the Early Universe requires moderate resolution (R ~3000) spectroscopy. Even in today's Time Domain Astrophysics (TDA) surveys (PTF, PS1, CRTS, etc.), spectroscopic followup is the bottleneck, but this pales in comparison with projections for LSST in the 2020s. We propose a Transient Spectroscopic Observatory (TSO) as a Probe-class mission incorporating a ~1.5m optical-nIR (0.5 – 2.4μm) telescope operating in geosynch orbit over the Western hemisphere equator where it is continuously visible to both LSST and White Sands for data downloads and commanding. TSO would provide rapid and deep (AB mag ~24.5 in 100s) imaging and identification for deep R ~3000 spectroscopy of "dark GRBs" triggered by full-sky GRB networks. This would permit the detailed studies of the evolution of the EOR, SFR (and PopIII stars) and evolution of structure at redshifts z ~6 – 15 that prompt nIR spectra of GRBs enables, but which ~8y of Swift followup nIR observations from the ground (VLT, Keck, Magellan) show cannot be done with sensitivities (typically K ≤22) limited by OH airglow. With LSST tiling of large projected ALIGO+ error boxes for nearby short GRBs out to ~200-300Mpc, Kilonovae as red transients could be found (~10% duty cycle for LSST) for identification and nIR spectroscopy by TSO for EM-GW studies of NS mergers with X-ray beaming unlikely to point towards us. Prioritized triggering of all classes of transients and extreme variables (stars, SNe, TDEs, AGN, Blazars) would be carried out in conjunction with LSST and other major surveys (radio – gamma-ray). TSO observations of the vast array of "non-TOO" variables, particularly obscured systems only detectable in the nIR, will enable the full astronomical community to participate in the upcoming era of TDA.

Semiconductor Compton Imager and Polarimeter for Nuclear Astrophysics

J. Eric Grove, Bernard F. Phlips, Eric A. Wulf, Charles D. Dermer, and Kent S. Wood (Naval Research Laboratory)

Abstract

A Semiconductor Compton Imager and Polarimeter (SCIP) is the only instrument capable of achieving >30 times better line and continuum sensitivities than the instruments of the Compton Gamma Ray Observatory and INTEGRAL missions in the energy range of 150 keV – 10 MeV. Such sensitivities are required for new discoveries in gamma-ray line emission from radioactive nuclei as tracers of the life cycle of matter, including the synthesis and distribution of the elements. A Probe-class mission can achieve these sensitivities, which enable detailed study of Type Ia supernovae, classical novae, and diffuse nuclear line emission from radionuclides, electron-positron annihilation, and nuclear excitations from the interaction of cosmic rays with molecular clouds, gas complexes, and supernova remnants. As a wide-field imager, SCIP has unprecedented sensitivity for the transient MeV sky, including such sources as gamma ray bursts (GRBs), galactic binaries, active galaxies, and solar flares. A sensitive Compton telescope is intrinsically a polarimeter, which has the potential, e.g., to discriminate photospheric and nonthermal radiation in GRB prompt emissions. Technology development on the semiconductor detectors and readout electronics for SCIP remains necessary. Here we present the scientific motivation and instrument concept to achieve these goals.

This work is supported by the Chief of Naval Research.

The High Energy X-ray Probe

Fiona Harrison (Caltech) and the HEX-P Team

Abstract

The high energy X-ray/low-energy gamma-ray band (1-200 keV) provides a unique window on phenomena ranging from the obscured accretion to nucleosynthesis and dynamics in supernova explosions. The NuSTAR SMEX mission has demonstrated the breadth of science possible with observations in this band. Joint observations with XMM, Chandra and Suzaku have also made it clear that quality measurements of the hard continuum is essential for proper interpretation of spectroscopic observations in the Fe-K band whether then be in emission or absorption. The High Energy X-ray Probe is a mission designed to extend the power of high-emery X-ray observations using high-angular resolution (10"), large collecting area (8000cm^2 at 6 keV) over a broad (0.5 - 200 keV) band. Through dedicated observations and surveys HEX-P will extend the resolved fraction of the cosmic X-ray background from 40 to 80%, providing a powerful probe of obscured accretion, and will address key questions such as when and how did supermassive black holes grow, and what happens near black holes? HEX-P will be an essential complement to Athena for broadband spectroscopic observations, and will be deployed in an orbit enabling simultaneous campaigns. As a probe class (<1B$) based on mature technologies HEX-P could launch next decade.

Gamma Ray Astronomy and the Cycles of Star Formation and Nucleosynthesis

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Abstract

One of the observational consequences of star formation is its associated copious production of gamma rays. The final stages of massive star evolution produce radioactive isotopes whose decay results in gamma ray lines and continuum radiation in the MeV regime. Type Ia supernovae follow star formation with a temporal delay of a few billion years, and their radioactive ejecta result in even stronger gamma-ray line and continuum emission. In addition, cosmic rays accelerated in supernova remnants produce further gamma rays via hadronic interactions with their circum-stellar environment. The galaxy thus produces a distributed gamma-ray luminosity density we observe as a diffuse galactic glow. The observed fluxes can be used to derive a reliable estimate of the galaxy-wide star formation rate, averaged over a million year time span. When explosive event yields are convolved with the cosmic star formation rate density, the above mentioned processes contribute to the extra-galactic (cosmic) background light (EBL). Active galaxies can produce the hard X-ray background as well as the flux observed in the GeV regime, but in the MeV band these sources fall significantly short. We discuss these connections, with emphasis on the MeV regime in which the emission from SNIa dominates that from core collapse supernovae, gamma-ray bursts, star forming galaxies, etc., but is still not fully able to account for the observed flux. The search for additional sources is ongoing, and advances in this area of high-energy astrophysics require a dedicated mission with greatly improved sensitivity. The MeV band is technically challenging, but deep exposures of the non-thermal universe will yield a better understanding of cosmic chemical evolution, in the Milky Way, local group of galaxies, and globally as a function of redshift. Gamma-ray astronomy can contribute uniquely to studies of the non-thermal environments of explosive cosmic cauldrons.

Extending Fermi-LAT discoveries: Compton-Pair Production Space Telescope (ComPair) for MeV Gamma-ray Astronomy

Elizabeth Hays (NASA/GSFC), John Mitchell (NASA/GSFC), Julie McEnery (NASA/GSFC), Alexander Moiseev (CRESST/NASA/GSFC and University of Maryland, College Park), and David Thompson (NASA/GSFC)

Abstract

The gamma-ray energy range from a few hundred keV to a few hundred MeV has remained largely unexplored, mainly due to the challenging nature of the measurements, since the pioneering but limited observations by COMPTEL on the Compton Gamma-Ray Observatory (1991-2000). This energy regime encompasses the transition between thermal and nonthermal processes, and accurate measurements are critical for answering a broad range of astrophysical questions. We are developing a concept for a discovery mission, ComPair (Compton-Pair Production Space Telescope), to investigate energies from 200 keV to > 500 MeV with high energy and angular resolution and with sensitivity approaching a factor of 100 better than COMPTEL. This instrument will be capable of detecting both Compton-scattering events at lower energy and pair-production events at higher energy. ComPair will build on the heritage of successful space missions including Fermi, AGILE, AMS and PAMELA, and will use well-developed space-qualified detector technologies including Si-strip and CdZnTe-strip detectors, heavy inorganic scintillators, and plastic scintillators.

Grating-based High-Resolution Soft X-ray Spectrometer for the X-ray Surveyor Mission Concept

Ralf K. Heilmann (MIT), Randall L. McEntaffer (U. Iowa) , Mark W. Bautz (MIT), and David P. Huenemoerder (MIT)

Abstract

Only a high-resolution grating spectrometer can answer important scientific questions posed by the Astro2010 Decadal Survey ("New Worlds New Horizons"). Topics as diverse as the growth of the large scale structure of the universe, its interaction with active galactic nuclei, kinematics of galactic outflows, or coronal emission from stars, can only be solved with spectroscopy at high enough resolution to both detect the X-ray signatures of plasma emission or absorption, and to measure their kinematic properties.

A dispersive spectrometer is a necessary instrument to include on the X-ray Surveyor, currently envisioned as an x-ray telescope with Chandra-like angular resolution, but about two orders-of-magnitude larger collecting area. The combination of high-efficiency gratings blazed to high orders and square-meter collecting-area optics will provide unprecedented performance in the x-ray band below ~ 2 keV where calorimeters provide insufficient energy resolution. Initial conceptual designs assume grating spectroscopy effective area on the order of 4,000 cm^2, and spectral resolving power R= l/Dl of up to 5,000, achieved by covering less than 50% of the optics aperture with retractable grating arrays. Both Critical-Angle Transmission (CAT) and Off-Plane Reflection Gratings (OPG) are candidate technologies. Readout cameras in the focal plane, offset from an imaging detector at the imaging focus, will detect the grating spectra and separate spatially overlapping diffraction orders of different wavelengths. A grating spectrometer is complementary to an imaging microcalorimeter instrument that provides similar energy resolution only in the harder x-ray band.

Critical-Angle Transmission (CAT) Gratings: Lightweight Large-Area Gratings for Efficient High-Resolution Spectroscopy on the X-ray Surveyor

Ralf K. Heilmann, Alexander R. Bruccoleri, Mark L. Schattenburg, and Mark W. Bautz (MIT)

Abstract

Wavelength-dispersive X-ray spectrometers provide unsurpassed spectral resolution at long wavelengths ($\lambda > \sim 6$ Angstrom, E < 2 keV) and will play an important role in fulfilling key science goals of future X-ray observatories. Understanding the growth of large-scale structure and its connection with the growth of supermassive black holes, the kinematics of galactic outflows, and coronal emission from stars will all require the sensitive, high-spectral-resolution spectroscopy that only grating spectrometers can provide.

The X-ray Surveyor – currently envisioned as an x-ray telescope with Chandra-like resolution, but roughly two orders-of-magnitude larger collecting area - therefore includes an X-ray Grating Spectrometer in its instrument complement. Initial conceptual designs assume effective area for grating spectroscopy on the order of 4,000 cm^2, and spectral resolving power R of up to 5,000, while covering less than 50% of the optics aperture with retractable grating arrays. Two linear readout cameras in the focal plane, offset from an imaging detector at the imaging focus, detect the dispersed photons and separate spatially overlapping diffraction orders of different wavelengths. Such an instrument will provide spectroscopy performance metrics orders of magnitude better than existing grating spectrometers on Chandra and XMM-Newton.

We have developed high-efficiency blazed transmission gratings that combine the advantages of traditional transmission gratings (low mass, relaxed alignment tolerances, high transparency for hard x-rays) and blazed reflection gratings (high diffraction efficiency, high resolving power due to blazing into higher diffraction orders). These so-called Critical-Angle Transmission (CAT) gratings are made from silicon-on-insulator wafers using a combination of advanced lithography, pattern transfer, and dry and wet etching techniques. The freestanding gratings consist of thin, ultrahigh aspect ratio silicon grating bars with an integrated Level-1 support mesh, and an external, coarser Level-2 mesh, resulting in mechanically stable, large-area grating "membranes". We report on the latest fabrication and x-ray test results of prototype CAT gratings.

Feedback on Galaxy and Cluster Scales in the Era or Imaging Calorimeters

Sebastian Heinz (University of Wisconsin - Madison)

Abstract

Energy input from AGN has become a critical ingredient in models of galaxy and cluster formation and evolution. On scales of galaxy clusters, imaging of jet-driven X-ray cavities by Chandra has revealed clear evidence for this feedback, while on galaxy scales, the nature of this feedback is speculative at best. Yet, even on cluster scales the details of energy injection are uncertain. The next generation of X-ray telescopes will be critical in answering the open questions, mainly: Are radio galaxies the primary agents of feedback in galaxies and clusters, and how does this feedback work in detail? I will discuss the challenges and the resulting technical requirements for X-ray telescopes to answer these questions.

Atom interferometric gravitational wave detection using heterodyne laser links

Jason M. Hogan and Mark A. Kasevich (Stanford)

Abstract

Gravitational wave (GW) detection with atom interferometry offers a promising alternative to traditional optical interferometry. Advantages of this approach include phase multiplication through multiple pulse sequences, proof mass resilience, laser frequency noise immunity and quantum back-action noise immunity.

We propose a scheme based on a heterodyne laser link that allows for long baseline gravitational wave detection using atom interferometry. We will compare the strain sensitivity curves for two long-baseline designs using Sr atoms and the LISA design sensitivity curve. The more conservative design uses an $L = 2 \times 10^9$ m baseline and the photon shot-noise limited laser link assumes 1 W laser power, a d = 30 cm diameter telescope, and a repetition rate $f_R = 0.2$ Hz. The long baseline allows for high sensitivity even though the design assumes conservative 2(hbar)k atom optics and atom shot-noise of $\delta\varphi a = 10-3$ rad/√Hz. A long interrogation time of T = 160 s is used to support low frequency sensitivity, but despite this long drift time the maximum wavepacket separation is bounded to < 2 m. The atom source design assumes ensembles of 7×10^6 atoms with a 20 pK longitudinal temperature, allowing for a $\Omega/2\pi = 60$ Hz Rabi frequency. Such design criteria are readily met using existing technology [7]. LMT techniques allow for enhanced sensitivity. This design is based on a 12(hbar)k interferometer sequence with an $L = 6 \times 10^8$ m baseline and improved phase noise $\delta\varphi a = 10-4$ rad/√Hz. Photon shot noise requirements are met using 1 W laser power and a d = 50 cm diameter telescope, giving Rabi frequency $\Omega/2\pi = 40$ Hz. The design has a sampling rate of $f_R = 1$ Hz. The increased phase sensitivity of this design allows for improved low frequency response even using a smaller interrogation time. Using T = 75 s, the maximum wavepacket separation is < 4 m.

We believe that recent progress in atom optics and optical clock technology can realistically enable such a detector. Many of the system level requirements (e.g. satellite bus position and angle jitter) are substantially reduced as compared with existing approaches. The strain sensitivities we will discuss are achieved using a single pair of satellites.

Synergies in Science in the MeV and TeV Gamma-ray Bands

Brian Humensky (Columbia University), for the CTA Consortium (www.cta - observatory.org)

Abstract

MeV gamma-ray astronomy has been more technically challenging to pursue compared to other energy regimes in gamma-ray astronomy. However, the motivation for MeV gamma-ray astronomy remains compelling. In this talk we will discuss the science connections in the gamma-ray sky between the 10-100 MeV band and ground-based very high energy (VHE; E > 100 GeV) instruments, including recent results and prospects for future observatories. The science connections include studies of supernova remnants, where the spectral shape in the MeV range is a powerful indicator of the type of cosmic rays producing radiation and the extension of the spectrum into the VHE range constrains the maximum particle energy and the diffusion properties of the particles. For active galactic nuclei, the combination of MeV through VHE gamma-ray spectra can completely determine the shape of the high-energy peak in the spectral energy distribution, discriminating between hadronic and leptonic production models for gamma-ray production and revealing the nature of the particle acceleration in the jets.

Advanced Energetic Pair Telescope (AdEPT),
a Medium-Energy Gamma-Ray Polarimeter

Stan Hunter (NASA Goddard Space Flight Center).

Abstract

Since the launch of AGILE and FERMI, the scientific progress in high-energy (E_γ > 200 MeV) gamma-ray science has been, and will continue to be dramatic. Both of these telescopes cover a broad energy range from ~20 MeV to >10 GeV. However, neither instrument is optimized for observations below ~200 MeV where many astrophysical objects exhibit unique, transitory behavior, such as spectral breaks, bursts, and flares. Hence, while significant progress from current observations is expected, a significant sensitivity gap will remain in the medium-energy regime (0.75 – 200 MeV) that has been explored only by COMPTEL and EGRET on CGRO. Exploring this regime with angular resolution near the kinematic limit and high polarization sensitivity requires a gamma-ray telescope design with a low density electron track imaging detector.

The medium-energy (~5 to ~200 MeV) **Advanced Energetic Pair Telescope (AdEPT)**, will achieve angular resolution of ~0.6° at 70 MeV, similar to the angular resolution of Fermi/LAT at ~1 GeV that brought tremendous success in identifying new sources. AdEPT will also provide unprecedented polarization sensitivity of ~1% for a 1 Crab source. The enabling technology for AdEPT is the **Three-Dimensional Track Imager (3-DTI)** a low-density, large volume, gas time-projection chamber with a 2-dimensional readout. The 3-DTI provides high-resolution three-dimensional electron tracking with minimal Coulomb scattering that is essential to achieve high angular resolution and polarization sensitivity.

We describe our ROSES/APRA funded program to build a 50×50×100 cm^3 AdEPT prototype, measure the angular resolution and polarization sensitivity of this prototype at an accelerator, and highlight a few of the key science questions that AdEPT will address.

Oscillations and Coherent Features in Black-Hole Accretion Disks: Distinguishing between the Relativistic Orbiting-Spot vs. Oscillating-Torus Models

V. Karas (Astronomical Institute of Prague), G. Torok (Institute of Physics, Silesian University), J. Horak (Astronomical Institute of Prague), P. Bakala (Institute of Physics, Silesian University), E. Sramkova (Institute of Physics, Silesian University), T. Pechacek (Astronomical Institute of Prague; Institute of Physics, Silesian University), K. Goluchova (Institute of Physics, Silesian University), M. Bursa (Astronomical Institute of Prague), K. Adamek (Institute of Physics, Silesian University)

Abstract

Variety of models of the kilohertz Quasi-Periodic Oscillations (QPOs) have been proposed but a general consensus is still lacking. We embark on the study from the viewpoint of role of coherent features persisting in a black hole accretion disk. Different theoretical schemes have been proposed to explain the origin of high-frequency QPOs from accreting neutron stars in low-mass X-ray binaries and stellar-mass black-holes. In the case of twin-peak sources, Fourier power-spectral density exhibits two dominant oscillation modes, often in the approximate ratio of small integers (3:2). Despite the rich phenomenology, base frequencies alone do not allow us to distinguish in a unique way among the most popular models. We discuss the harmonic content predicted by two competing scenarios, namely, the orbiting spot model and the oscillating torus model. By employing a ray-tracing code, we study the relativistic regime where the emerging radiation signal is influenced by effects of strong gravity (energy shifts and light bending). We consider spots moving on slightly non-circular trajectories in an accretion disk, and tori oscillating with fundamental modes. The harmonic content of the observed signal can allow us to reveal the ellipticity of the orbits and discriminate between the scheme of orbiting spots and the case of an oscillating torus. We estimate the required signal-to-noise ratio of the model light curves.

Tidal Disruption Events near a Supermassive Black Hole in an Oblate Dense Nuclear Star Cluster: On Expected Relativistic Spectral Line Profiles from a Remnant Accretion Disk

V. Karas (Astronomical Institute of Prague), M. Dovciak (Astronomical Institute of Prague), D. Kunneriath (Astronomical Institute of Prague), J. Svoboda (Astronomical Institute of Prague), W. Yu(Shanghai Astronomical Observatory), W. Zhang(Shanghai Astronomical Observatory), L. Subr (Astronomical Institute, Charles University)

Abstract

We explore a possibility that tidal disruption events (TDEs) near a dormant supermassive black hole (SMBH) can give rise to spectral features of iron in 6-7 keV X-ray signal: a general-relativistic (GR) spectral-line profile emerges from a remnant accretion disk illuminated and ionised by a hot corona, where the latter is produced by delayed accretion of remnant material from the destroyed star. This could provide a unique way to determine parameters of the system. We consider a scenario where the nuclear stellar cluster (NSC) contains a dusty torus and acquires an oblate shape in its inner region (within the sphere of gravitational influence of SMBH). Resonance mechanisms of the stellar motion help to increase the orbital eccentricity for some stars in NSC and bring them close to the tidal radius, where they can give rise to TDEs (Wenda Zhang et al., 2015, ApJ accepted).

The Scientific Potential of X-ray and Gamma-Ray Polarimetry from Sub-keV to GeV Energies

Fabian Kislat (Washington University and the McDonnell Center for the Space Sciences)

Abstract

X-ray and gamma-ray polarimetry can provide geometrical information about kilometer-sized objects thousands of light years away. In this talk, I will review the science drivers for X-ray polarimetric observations in the soft X-ray regime (0.1-2 keV), the intermediate and hard X-ray regimes (2-500 keV), and in the gamma-ray regime (500 keV-300 GeV). At soft and intermediate X-ray energies, the polarization of the thermal emission from black hole and neutron star accretion disks and from magnetars can be studied. The polarization of intermediate and hard X-rays can probe the inner structure of accretion flows covering all the major accretion flow components (disk, corona, jet) as well as the properties of strongly curved spacetime. Pulsar, neutron star, and magnetar observations can be used to probe exotic strong-magnetic field processes inside and close to these extreme objects. Last but not least, gamma-ray polarimetry gives information about the most extreme particle accelerators in the Universe, and allows us to probe quantum electrodynamics and Lorentz Invariance in regimes, which cannot be probed in the laboratory.

Cosmic Dawn Science Interest Group

Joseph Lazio (Jet Propulsion Laboratory, CalTech)

Abstract

Cosmic Dawn was identified as one of the three science objectives for this decade in the New Worlds, New Horizons Decadal report, and it will likely continue to be a research focus well into the next decade. Cosmic Dawn refers to the interval during which the Universe transitioned from a nearly completely neutral state back to a nearly fully ionized state and includes the time during which the first stars formed and the first galaxies assembled.

The Cosmic Dawn Science Interest Group (SIG) was formed re- cently under the auspices of the Cosmic Origins Program Analysis Group (COPAG), but there are likely to be synergies with the Physics of the Cosmos Program and the high-energy community. For instance, a small number of γray bursts from early generations of stars have been detected and studies of the first black holes are a science target of future X-ray telescopes.

This presentation is designed to bring the Cosmic Dawn SIG to the attention of the high-energy community and invite participation and engagement.

Part of this research was carried out at the Jet Propulsion Laboratory, Cali- fornia Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Gravitational Waves at Nanohertz Frequencies:
The North American Nanohertz Observatory for Gravitational Waves

Joseph Lazio (JPL) on behalf of NANOGrav

Abstract

The direct detection of gravitational waves (GWs) would represent a confirmation of their existence that any viable theory of gravity would have to reproduce, and it is an integral part of the Physics of the Cosmos program. In the nanohertz frequency band, the expected source of GWs are supermassive black hole (SMBH) binaries, with the additional possibility of a contribution from cosmic strings. SMBH binaries from mergers of galaxies will most likely form an ensemble, creating a stochastic GW background with the possibility of a few nearby/massive sources that will be individually resolvable. The recognized approach for nanohertz GW detection and study is via a pulsar timing array (PTA)—an array of precisely timed millisecond pulsars, spread across the sky.

The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) currently observes an array of 45 millisecond pulsars. A significant fraction of these millisecond pulsars were first identified by Fermi, and, as new high-quality pulsars are discovered, they are added to the program. Timing is undertaken at the Arecibo Observatory and the Green Bank Telescope, with potential future contributions from the Very Large Array and NASA's Deep Space Network. The typical observational cadence is 20 to 30 days, with arrival times for nearly all pulsars determined with precision better than 1 μs, and, in the best cases, better than 100 ns. We describe the NANOGrav nine-year data release and the resulting limits on nanohertz GWs.

NANOGrav studies of GWs could influence future space-based interferometric missions, by providing information about the extent to which SMBH binaries merge, and NANOGrav has benefited from Fermi and will likely benefit from future γ-ray missions.

Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Possible Space-Based Gravitational Wave Observatory Mission Design

Jeffrey Livas (NASA Goddard Space Flight Center)

Abstract

A rich spectrum of astrophysical gravitational-wave sources is expected at frequencies between 0.0001 and 0.1 Hz. A space-based observatory is required to access these sources to avoid large gravity gradient (Newtonian) noise at low frequencies, to take advantage of a benign thermal environment, and to allow the construction of large measurement baselines that are well matched to the wavelengths of the sources. The Laser Interferometer Space Antenna (LISA) has long been the reference mission to cover this science with an international partnership between NASA and ESA. Budget constraints have forced both agencies to search for revised mission concepts with a lower cost point. A possible mission design compatible with the cost constraints of the L3 Cosmic Visions Opportunity will be described based on the SGO-Mid concept developed for the 2012 Gravitational Wave Mission Concept Study. Cost and risk tradeoffs will be discussed, as well as a range of options to maximize the science return.

The Advanced Scintillator Compton Telescope (ASCOT)

M. L. McConnell, P. F. Bloser, J. M. Ryan, J. S. Legere (University of New Hampshire)

Abstract

We will describe our ongoing work to develop new medium-energy gamma-ray instrumentation by constructing and flying a balloon-borne Compton telescope using advanced scintillator materials combined with silicon photomultiplier readouts. There is an urgent need in high-energy astronomy for a medium-energy gamma-ray mission covering the energy range from approximately 0.4 - 20 MeV to follow the success of the COMPTEL instrument on CGRO. Given the current budgetary environment, we believe that directly building on the legacy of COMPTEL, using relatively robust, low-cost, off-the-shelf technologies, is the most promising path for such a mission to become reality in the foreseeable future. Fortunately, high-performance scintillators, such as Lanthanum Bromide ($LaBr_3$), Cerium Bromide ($CeBr_3$), and p-terphenyl, and compact readout devices, such as silicon photomultipliers (SiPMs), are already commercially available and capable of meeting this need. We have conducted two balloon flights of prototype instruments to test these technologies. The first, in 2011, demonstrated that a Compton telescope consisting of an liquid organic scintillator scattering layer and a $LaBr_3$ calorimeter effectively rejects background under balloon-flight conditions, using time-of-flight (ToF) discrimination. The second, in 2014, showed that a telescope using an organic stilbene crystal scattering element and a $LaBr_3$ calorimeter with SiPM readouts can achieve similar ToF performance. We are now beginning work on a much larger balloon instrument, an Advanced Scintillator Compton Telescope (ASCOT) with SiPM readout, with the goal of imaging the Crab Nebula at MeV energies in a one-day flight. If successful, this will demonstrate that the energy, timing, and position resolution of this technology are sufficient to achieve an order of magnitude improvement in sensitivity in the medium-energy gamma-ray band, were it to be applied to a ~1 cubic meter instrument on a ULDB or Explorer platform.

The next generation of X-ray reflection gratings

Randall McEntaffer (University of Iowa)

Abstract

Future NASA X-ray observatories will shed light on a variety of high-energy astrophysical phenomena. Off-plane reflection gratings can be used to provide high throughput and spectral resolution in the 0.3-2.0 keV band, allowing for unprecedented diagnostics of energetic astrophysical processes. A grating spectrometer consists of multiple aligned gratings intersecting the converging beam of a Wolter-1 telescope. To achieve the performance requirements of future missions, these gratings must have a high precision, custom groove profile and be aligned to overlap each spectrum at the focal plane. Here we report on the progress made on the development of these gratings. We have identified a novel grating fabrication method and have performed X-ray testing of prototype gratings. The performance of these gratings is consistent with high throughput and resolution. Furthermore, we have quantified our alignment tolerances and investigated alignment strategies and module mounts. Future plans for flight opportunities of payloads utilizing an off-plane grating spectrometer are discussed.

The Chandra Source Catalog: Release 2.0

Michael Nowak (MIT-Kavli Institute & Chandra X-ray Science Center), on behalf of the Chandra Source Catalog Team

Abstract

The first release of the Chandra Source Catalog in 2009 presented source properties for nearly 95,000 sources from ~136,00 detections from the first decade of observations by the Chandra X-ray Observatory. Release 1.1 in 2010 included ~107,000 sources from ~158,000 detections. Chandra's exquisite angular resolution and low background allows for source detections over a wide range of fluxes and source types: relatively nearby X-ray active stars, compact objects within our own galaxy, populations of X-ray emitting sources in external galaxies, and distant Active Galactic Nuclei. The first catalog release included estimates of source position (many with sub-arcsecond accuracy), source flux in multiple energy bands, X-ray colors, variability properties, and estimates of source extent. Detections and source properties were determined for single observations, and then sources were cross-matched across multiple observations to create "master source" properties, such as mean X-ray flux/colors and long term variability.

Release 2.0 of the catalog will fundamentally change the paradigms for source detection and characterization. Detections will be performed on multiple observations (sharing common pointings within 1 arcminute of each other) stacked together, and fainter sources will be included in the catalog. Characterization will in part be achieved by fitting point source and extended source models to individual source data, including direct application of the Chandra Point Spread Function (PSF). Improved models of the Chandra background will be applied, and for the first time the catalog will include properties from extended emission regions. Along with the addition of public Chandra data through 2014, the Release 2.0 catalog will contain ~400,000 detections.

Processing has begun on the release 2.0 catalog. In this poster we describe the processing steps and algorithms for source characterization, and outline our plans for the catalog release.

Probing the radio mode AGN feedback cycle in the X-ray

Paul Nulsen (Harvard-Smithsonian Center for Astrophysics).

Abstract

Although there is good empirical evidence that radio AGN (active galactic nuclei) regulate the growth of massive galaxies, we are far from understanding how this process works. Feedback models generally require the AGN to be fueled by cooled or cooling gas, with accretion of cooled gas favored by theory and observations. At present, there is little direct evidence of hot gas cooling to low temperatures. This presentation will discuss what X-ray observations at high spatial and spectral resolution can tell us about the interaction between a radio AGN and its hot atmosphere. The main focus will be the thermally unstable cooling of hot gas, but there will also be some discussion of what we may learn about how AGN energy is transferred to the gas.

The JEM-EUSO Mission

Angela V. Olinto (University of Chicago) for the JEM-EUSO collaboration

Abstract

Giant ground-based observatories have had limited statistics to unveil the sources of ultrahigh energy cosmic rays (UHECRs) that reach above 10^20 eV (100 EeV). Space missions can reach much higher exposure to the extreme energy cosmic rays (EECRs; E > 60 EeV) by simultaneously monitoring a much larger volume of the atmosphere from above. The Extreme Universe Space Observatory (EUSO) at the Japanese Experiment Module (JEM) is designed to increase the sensitivity to EECRs by one order of magnitude. JEM-EUSO will measure the spectrum and angular distribution of EECRs over the full sky enabling the identification of their sources. A wide-field (60 degrees) telescope with a diameter of about 2.5 m will look down from the International Space Station (ISS) onto the night atmosphere to detect near UV photons (330-400nm) from fluorescent and Cherenkov emission of extensive air showers produced by EECRs. The arrival direction map with hundreds of events above 60 EeV will allow the identification of the nearest EECR sources with known astronomical objects and the understanding of the physics of the acceleration and propagation mechanisms. The observed energy spectra and sky map can test the GZK process and/or determine the maximum energy of astrophysical accelerators. Neutral components (neutrinos and gamma rays) may also be detected, if their fluxes are high enough. The JEM-EUSO mission is being planned for a SpaceX Falcon 9 rocket launch and a SpaceX Dragon delivery to the JEM of the ISS.

A Wide-Field High-Angular Resolution X-ray Mission after Chandra: Design and Optics Technology

G. Pareschi (INAF/Brera Astronomical Observatory), O. Citterio (INAF/Brera Astronomical Observatory), M. Civitani (INAF/Brera Astronomical Observatory), S. Basso (INAF/Brera Astronomical Observatory), P. Conconi (INAF/Brera Astronomical Observatory), M. Ghigo (INAF/Brera Astronomical Observatory), G. Tagliaferri (INAF/Brera Astronomical Observatory), M. Gubarev (NASA Marshall Space Flight Center), J. Kolodziejczak (NASA Marshall Space Flight Center), S. O'Dell (NASA Marshall Space Flight Center), B. Ramsey (NASA Marshall Space Flight Center), J. Roche (NASA Marshall Space Flight Center), M. Weisskopf (NASA Marshall Space Flight Center)

Abstract

The implementation of an X-ray mission with high imaging capabilities, similar in angular resolution to those achieved with Chandra (<1 arcsec Half Energy Width, HEW), but with a larger effective area and field of view, is very attractive, even if very challenging. Towards that end, we propose a wide-field mirror fabrication technique based on precise direct grinding, figuring and polishing of thin (a few mm) shells with innovative deterministic polishing methods. This process may be followed by a final correction via ion figuring to obtain the desired accuracy. For this purpose, a temporary stiffening structure is used to support the shell from the polishing operations up to its integration in the telescope supporting structure. This paper deals with the technological process under development, the results achieved so far and some mission scenarios based on this kind of optics, aiming to achieve an effective area more than 10 times larger than Chandra and an angular resolution of 1 arcsec HEW on axis and of a few arcsec off-axis across a large field of view (1 degree in diameter), similar to the previously proposed mission WFXT.

Lessons Learned from the NASA X-ray Mission Concepts Study

Rob Petre (NASA / GSFC)

Abstract

In 2012, NASA sponsored a year-long X-ray Mission Concepts Study to define missions that could fulfill a substantial fraction of the IXO scientific objectives at the cost of $1B or less (i.e., probe class missions). The inputs to this study, provided by the community via white paper responses to an RFI, included a broad range of concepts covering a wide range of instrumentation and a cost range from a few hundred $M to over $2B. The study itself produced well-defined concepts for four missions. The two least expensive of these fall squarely into the probe class and are highly complementary to Athena. The final report for this study can be found at http://pcos.gsfc.nasa.gov/studies/x-ray-mission.php.

This presentation summarizes the input to and the output from the X-ray Mission Concepts Study. It also offers lessons learned regarding studies such as these, which are highly relevant as probe class missions are formulated as input to the 2020 Decadal Survey, particularly with regard to cost and risk assessment.

Recent Advances in Reflective Hard X-ray / Soft Gamma-Ray Optics and the Prospects for Future Astrophysical Missions

Michael J Pivovaroff (Lawrence Livermore National Laboratory)

Abstract

Over the last forty years, reflective x-ray telescopes have enabled detailed observations of the 0.1-10 keV x-ray sky and dramatically improved our knowledge of astrophysical processes, cosmology and fundamental physics. Focusing optics overcome intrinsic limitations of other techniques like absorptive collimation, and their use above 10 keV should revolutionize our understanding of the hard X-ray Universe. The early science results from NASA's NuSTAR, the first satellite to provide true-focusing from up to 78 keV, show the promise of extending this technology above 100 keV.

In this presentation, I will discuss recent advances in multilayer x-ray optics that have demonstrated excellent performance at energies up to 640 keV. This work, undertaken for nuclear non-proliferation missions, involves the development and optimization of multilayer coatings comprised of tungsten carbide and silicon carbide, extensive metrology and testing at synchrotron facilities, including two measurement campaigns using hard X-ray beamlines at the European Synchrotron Radiation Facility. After presenting results, published in *Optics Express*, *Nuclear Instruments and Methods A,* and *Physical Review Letters*, from our active research program at Lawrence Livermore, I will describe how reflective multilayer-coated mirrors could be used for a future satellite mission that could provide sub arc-minute imaging beyond 0.5 MeV.

Spectral Simulations of 1E0102.2-7219 and N132D for the ASTRO-H SXS and Athena X-IFU

Paul P. Plucinsky (Smithsonian Astrophysical Observatory)

Abstract

We present spectral simulations of the bright, line-dominated spectra of the Magellanic Cloud SNRs 1E0102.2-7219 and N132D with the currently available response files for the ASTRO-H Soft X-ray Spectrometer (SXS) and the Athena X-ray Integral Field Unit (X-IFU). The spectral models have been developed by the International Astronomical Consortium for High Energy Calibration (IACHEC). The IACHEC models are empirical by nature based on the high-resolution spectra obtained by the Reflection Gratings Spectrometer (RGS) on XMM-Newton and the High Energy Transmissions Gratings (HETG) on the Chandra X-ray Observatory and are intended to facilitate the calibration of the current generation of moderate resolution CCD detectors. But since the models are based on high resolution gratings spectra, they are useful for exploring the performance of the next generation of high-resolution, non-dispersive spectrometers. We compare the expected results for the SXS and X-IFU for representative observations.

Status of X-ray sensitive Si hybrid CMOS detector development at Penn State

Zachary Prieskorn (The Pennsylvania State University), Abraham D. Falcone (PSU), Christopher V. Griffith (PSU), David N. Burrows (PSU).

Abstract

X-ray sensitive Si hybrid CMOS detectors (HCDs) have the potential to replace CCDs as the focal-plane detector of choice in future X-ray observatories due to their fast readout, low power usage, and inherent resistance to radiation & micrometeoroid damage. Since 2005, Penn State has worked with Teledyne Imaging Sensors (TIS) to optimize their HCDs for use as X-ray detectors. The highest-TRL HCDs have significant heritage from the TIS HyViSI line of detectors. Detectors with 18 & 36 μm square pixels and 1k´1k & 2k´2k pixel^2 formats have been successfully demonstrated by Penn State, with measurements of their performance characteristics including energy resolution, read-noise, dark current, and inter-pixel capacitance (IPC). These detectors are mission-ready and have been proposed for potential X-ray observatories. Penn State also has two HCD development programs with X-ray specific CMOS architecture, taking the TIS HyViSI capabilities a step further. The Speedster-EXD is an X-ray sensitive HCD with low noise, low IPC, and in-pixel signal chains allowing sparse read out (only pixels with charge deposited from X-ray events are read out of the detector). Sparse read out enables the Speedster-EXD to handle very high count rates, up to ~100,000 events/sec. Speedster-EXD detectors with 40 μm square pixels and a 64´64 pixel^2 format have already been characterized in our lab. The next step in this program is underway with development of a follow-up large format detector. Another development program will provide X-ray specific CMOS architecture with small pixels (< 15 μm square). These detectors are currently in production and will have high read out speeds, low read-noise, low IPC, and in-pixel CDS. These detectors could provide HCD capabilities for future X-ray missions with high throughput and sub-arcsecond spatial resolution. HCDs provide unique capabilities for future X-ray observatories; mission-ready HyViSI detectors are available now and could be proposed for upcoming CubeSat or Explorer missions, while more capable detectors are in development that will be suitable for missions with extremely high count rates and fine spatial resolution.

NuSTAR Observations of Starburst Galaxies

Andrew Ptak (NASA/GSFC), A. Hornschemeier (NASA/GSFC), D. Wik (JHU/GSFC), B. Lehmer (JHU/GSFC), M. Yukita (JHU/GSFC), T. Maccarone (Texas Tech. U.), A. Zezas (U. Crete), T. Venters (NASA/GSFC), V. Antoniou (CfA),

Abstract

NuSTAR, the first satellite with hard X-ray focusing optics, opens up the possibility to not only detect starburst galaxies above 10 keV for the first time but also characterize their hard X-ray properties. Here we present an overview of a NuSTAR program to survey seven normal/starburst galaxies: NGC 253, M82, M83, NGC 3256, NGC 3310, Arp 299, and M31. We also discuss data analysis strategies. All galaxies have been observed coordinated with either Chandra or XMM-Newton or both. The main results of these observations were: we characterized the typical starburst spectrum above 10 keV and showed that the spectrum is soft (photon index ~ 3) above 7 keV and determined that individually detected sources are generally black holes in a "transition" accretion state, and variability on time scales of weeks to months is typically detected. In the case of NGC 253 we isolated decomposed the unresolved hard X-ray emission between background, unresolved binaries and truly diffuse flux and found that the diffuse flux upper limit is marginally above model predictions for inverse-Compton scattering of IR photons by cosmic rays.

The Wide Field X-ray Telescope

Andrew Ptak (NASA/GSFC)

Abstract

A high-priority theme from the NWNH Decadal Survey report was the need for surveys to understand the high-redshift universe and its evolution to the present day. A dedicated, high-throughput wide-field X-ray mission is critically needed to complete this picture. Here we discuss the design and science goals of the Wide-Field X-ray Telescope, a probe-class mission that would have an average PSF of < 5" over a one-degree FOV and be well matched to LSST and WFIRST in sensitivity. Thanks to the huge cosmological volumes that WFXT will cover, its main science goals will be to find and characterize the earliest AGN at z=6-8, groups out to z~1 and clusters out to z~2, and to study the evolution of these populations with very large samples (e.g., millions of AGN). WFXT will also detect large numbers of normal galaxies and Galactic stars and will study their properties as a function of environment and age. The WFXT surveys will be built up over time from multiple scans making it a exceptional tool for time-domain astronomy. This will include detecting X-ray counterparts to Advanced LIGO events, LSST-triggered transients, tidal disruption events, supernovae, and potentially new classes of transient objects. WFXT will also characterize the long-term variability of AGN and X-ray binaries. A MSFC Advanced Concept Office study for WFXT was performed and the results will be presented, which will include this preliminary design and cost estimates.

BurstCube: A CubeSat for Gravitational Wave Counterparts

J. L. Racusin (NASA GSFC), J. S. Perkins (NASA GSFC), M. S. Briggs (University of Alabama, Huntsville), G. A. de Nolfoj (NASA GSFC), J. Krizmanic (NASA GSFC), V. Connaughton (USRA), J. E. McEnery (NASA GSFC)

Abstract

We present BurstCube, a novel CubeSat that will detect and localize Gamma-ray Bursts (GRBs). BurstCube will detect both long GRBs attributed to the collapse of massive stars, and short GRBs that are the result of a binary neutron star merger, which are also predicted to be the counterparts of gravitational wave sources soon to be detectable by advanced LIGO/Virgo, as well as other gamma-ray (10-1000 keV) transients. BurstCube contains 4 CsI scintillators coupled with arrays of compact low-power Silicon photomultipliers (SiPMs) on a 6U CubeSat incorporating in-house front-end electronics for large-area arrays of SiPMs, off-the-shelf spacecraft components and a straightforward design and implementation. BurstCube will potentially complement existing facilities such as Swift and Fermi in the short term, and provide a means for GRB detection, localization, and characterization in the interim time before the next generation future gamma-ray mission flies, as well as space-qualify SiPMs and test technologies that may be used on the next generation gamma-ray probe or flagship. The ultimate configuration of BurstCube is to have a set of ~10 BurstCubes to provide all-sky coverage to GRBs for substantially lower cost than a full-scale mission.

The X-ray Surveyor Mission Concept Telescope: Optical Design and Optics Technologies

Paul Reid (Smithsonian Astrophysical Observatory), Brian Ramsey (NASA Marshall Space Flight Center), Ryan Allured (SAO), Sagi ben Ami (SAO), Carolyn Atkins (MSFC), Daniel Baldwin (SAO), David Broadway (MSFC), Vincenzo Cotroneo (SAO), Mikhail Gubarev (MSFC), Edward Hertz (SAO), Kiranmayee Kilaru (MSFC), Vanessa Marquez (SAO), Stuart McMuldroch (SAO), Stephen O'Dell (MSFC), Daniel Schwartz (SAO), Alexey Vikhlinin (SAO)

Abstract

The X-ray Surveyor (XRS) telescope will achieve the dual, and until now, conflicting requirements of large effective area and high angular resolution. We present a preliminary design for the telescope optics, and the results of several ray-tracing studies in which the benefits of Wolter-Schwarzschild designs are compared with the [to date] more common Wolter-I designs. We show effective area estimates as a function of energy, the point spread function along with its field dependence, and vignetting versus off-axis angle. The results of the studies show effective area of > 2 square meters at 1 keV, with a field-dependent point spread function smaller than 1 arcsecond half power diameter over a field-of-view exceeding 10 arcminutes diameter. This large, sub-arcsecond imaging field of view will greatly enhance the observational power of X-ray Surveyor.

We also review a number of promising technologies for the fabrication of the lightweight XRS mirrors incorporating active and passive methods to achieve desired imaging; adjustable X-ray optics, differential deposition, low stress single crystal silicon mirrors, ion implantation, and magneto-strictive optics. Results of recent experiments correcting mirror figure via piezoelectric thin film "actuators" deposited directly on the back of test mirrors will be shown, as well as results of figure correction using differential deposition - a computer controlled spatially varying sputter deposition process. System level imaging error budgets are used to establish the requirements for the different manufacturing processes. Near term development plans, technology roadmaps, and key technology milestones are also discussed.

Prospects for detecting black hole seeds and measuring cosmic black hole growth with current and future X-ray telescopes

Kevin Schawinski (ETH Zürich; Institute for Astronomy)

Abstract

X-ray astronomy can answer to major outstanding questions in astrophysics: i) when and how did the first black holes form, and ii) how do black holes grow over cosmic time.

The existence of z~6-7 quasars has led to the development of models for the formation of very massive seeds at very high redshift. Yet searches for massive black holes in normal galaxies at z>5 have mostly come up empty, and limits from Chandra survey are starting to constrain seed formation and early growth scenarios. I outline the current state of the search for black hole seeds and how Chandra and future missions will contribute.

While X-ray surveys are measuring the X-ray luminosity function of AGN to increasingly faint flux levels, out knowledge of the underlying black hole mass function and distribution of Eddington ratios is limited to what we learn from a handful measurements of broad-line quasars. Using X-ray variability over long timescales, it may be possible to measure black hole masses for a large sample of X-ray AGN and I briefly describe what could be achieved with existing and future X-ray missions.

Distribution of Matter X-ray Surveys within the next 20 Years

Norbert Schulz (Kavli Institute for Astrophysics and Space Research, MIT)

Abstract

The chemical evolution of the Universe embraces aspects that reach deep into modern astrophysics and cosmology. We want to know how present and past matter is affected by various levels and types of nucleosynthesis and stellar evolution. Three major categories were identified:
1. The study of pre-mordial star formation including periods of super-massive black hole formation.
2. The embedded evolution of the intergalactic medium (IGM).
3. The status and evolution of stars and the interstellar medium (ISM) in galaxies.
Today a fourth category relates to our understanding of dark matter in relation to these three categories.

The X-ray band is particularly sensitive to K- and L-shell absorption and scattering from high abundant elements like C, N, O, Ne, Mg, Si, S, Ar, Ca, Fe, and Ni. Like the Lyman alpha forest in the optical band, absorbers in the IGM produce an X-ray line forest along the line of sight in the X-ray spectrum of a background quasar. Similary bright X-ray sources within galaxies and the Milky Way produce a continuum, which is being absorbed by elements in various phases of the ISM.

High resolution X-ray absorption surveys are possible with technologies ready for flight within 5 years:
==> high efficiency X-ray optics with optical performance << 5"
==> high resolution X-ray gratings with R > 3000 for E < 1.5 keV
==> X-ray micro-calorimeters with R > 2000 for E > 1.5 keV
1. Within the next 3 - 5 years we utilize sub-orbital rockets and obtain sufficient technology readiness.
2. Within the next 5-10 years smaller mission opportunities can be realized to pursue some preliminary surveys.
3. Beyond 10 years we should be able to perform proper and deep surveys with the power of a Generation-X-type X-ray observatory.
The vision for the next 20 years needs to lead to means and strategies which allows us to perform such absorption surveys as effectively as surveys are now or in very near future quite common in astronomy pursued in other wavelength bands such as optical, IR, and sub-mm.

PANGU: a high resolution sub-GeV gamma-ray telescope

Meng Su (MIT) on behalf of the PANGU collaboration

Abstract

I will briefly describe a proposed gamma-ray space mission to the joint ESA-CAS space mission program. The highly successful Fermi Gamma-ray Space Telescope has proved the great potential of studying astrophysics, cosmology and fundamental physics in high energy gamma rays. One area of improvement is in the 10 MeV to 1 GeV region, where the point spread function of Fermi is limited by the presence of the Tungsten converters. Another area is the polarization measurement which has not yet been achieved at this energy range. It is also crucial to have a gamma-ray all sky survey mission running in parallel with missions covering higher energy range from tens of GeV to PeV, including HERD, CTA, and LHAASO. PANGU (PAir-productioN Gamma-ray Unit) will use a fully active tracker with thin silicon strip detectors to achieve a PSF of $\sim 1°$ at 100 MeV, which is a factor of five better than Fermi. PANGU will enhance our capability to search for dark matter annihilation signal from the Galactic center, besides many other science goals it could achieve. PANGU has now been selected as the only high energy astrophysics mission candidate for this joint ESA-CAS space mission.

SMILE: Sub-MeV/MeV gamma-ray survey using electron-tracking Compton camera loaded on balloon

Atsushi Takada (Kyoto University).

Abstract

To open the window of MeV gamma-ray astronomy, from hundreds of keV to ten MeV, we are developing an electron-tracking Compton telescope (ETCC), which consists of a gaseous three dimensional electron tracker and pixel-scintillator array as a photo-absorber. Because the electron tracking, which is different from COMPTEL, supplies three new parameters (two directional angles and track length), an ETCC can obtain clear images by adding definition of scattering plane (scatter plane deviation: SPD) with scattering angle (angular resolution measure: ARM) measured in standard Compton telescopes, and it has quite powerful background rejection tools of Compton kinematics and energy loss rate. By these features, the distribution of point spread function (PSF) of ETCC is several times sharper than that of conventional Compton telescopes. SPD is an essential to define PSF of Compton imaging quantitatively. Such a well-defined PSF is able to provide reliable sensitivity without use of optimizing algorithm.

To verify the ability of ETCC, we have a plan of above balloon experiment: Sub MeV gamma-ray Imaging Loaded-on-balloon Experiment (SMILE). The first balloon loading a 10 cm-cube ETCC was successful to obtain the fluxes of diffuse cosmic and atmospheric gamma rays with background rejection. Now we are testing a 30 cm-cube ETCC with 1 atm Ar for the next experiment (SMILE-II) observing the Crab nebula with >5 sigma for 4 hours observation. Here we have attained the SPD resolution to ~50 degrees, which gives 6 times better significance than that of conventional method. In addition, we measured the modulation factor of the ETCC using synchrotron facility, and obtained to 0.6 for 130 keV without imaging.

Now we are studying how imaging improves the modulation factor. After SMILE-II, the sensitivity of 30 cm-cube ETCC with 3 atm CF4 gas (SMILE-III) is expected to reach 5 times better than that of COMPTEL in one month balloon, and we will start galactic survey with long duration balloons. By a calculation, an extension of the ETCC will attain a good PSF of <2 degrees including the half of event distribution, which enables a 50 cm-cubic ETCC with 3 atm CF4 in space to reach to the sensitivity of a few mCrab during 10^6 sec. In this presentation, we talk about the performance of ETCC and new astrophysics in near future by high sensitive observation of MeV gamma rays.

"And the remaining 22 photons":
Lessons from the Past for Future High Energy Space Missions

Virginia Trimble (U.C Irvine and LCOGT)

Abstract

The CMB is, of course, 50 years old in 2015, and general relativity 100, but it is also the 55th anniversary of Alessandro Braccesi looking for gamma rays from the radio source Cyg A, using a nuclear emulsion stack that had been meant for cosmic rays, and of Tom Cline building the first detector actually meant for gamma rays of cosmic origin. High energy astrophysics from above the atmosphere has always been expensive (i.e. "big" at least in budgets) compared to most ground-based astronomical activities, and so has required Heroes (and a few Heroines) who were able to herd their cat-like colleagues -- first a few, then tens, later hundreds, and thousands – into supporting one possibility out of many. Some of the stories are well known, like the rocket flight that was supposed to look for X-rays from the moon, but actually discovered Her X-1 and a background. Some perhaps less so -- those 22 photons; and did Ken Greisen actually discover a gamma-ray flare from the Crab Nebula? Many of the heroes, from Arnold (Jim) to Zwicky (Fritz) are no longer here to explain how they made things happen. Zwicky sometimes by opposing them! And some of the lessons may not be entirely meritorious: for instance, it helps of high-provile theorists consent to predict what you want to look for. But "mission concepts," "precursor observations," and "enabling technologies" go back to the beginnings of our field, and I would like to tell some of the stories.

A modest proposal for an X-ray surveyor mission

M. P. Ulmer (Northwestern Univ.), Richard Massey (Univ. of Durham, UK), David Harvey (EPFL, Switzerland), Youwei Yao (Northwestern Univ.), Christophe Adami (LAM, France) , Doug Clowe (Ohio Univ.)

Abstract

A strong science case as well as a feasible and affordable technology are needed to achieve a high enough ranking in the next Decadal Survey. Here we suggest such a mission which is an X-ray “probe” (< $1B) satellite. The concept is based on the primary science goal of exploring the nature of Dark Matter (DM) by combining weak lensing from Euclid and WFIRST-AFTA with our proposed X-ray mission. We will demonstrate why Chandra-like angular resolution is needed to carry out our analysis. Further, we will present a design path that will achieve the affordable goal of more than 10x Chandra. The design addresses the affordability issue by making a high energy cutoff in the 1-2 keV range. Technologies that could produce the necessary optics are discussed elsewhere in the meeting and only briefly mentioned here. Beyond the major science goal of understanding the nature of DM, we give a few examples of where, in general, Chandra angular resolution is so desirable, but that with Chandra we are photon-starved. From these examples we show why more than10x Chandra with Chandra-like resolution will be a boon to X- ray astronomers for many projects.

Advances in post-fabrication correction of replicated X-ray optics

M. P. Ulmer, Y. Yao, X. Wang, J. Cao, and S. Vaynman (Northwestern Univ.)

Abstract

Since the early 2000's, the breath taking pictures from the Chandra Observatory, have left X-ray astronomers wanting more area with the same angular resolution at an affordable price. The affordability requirement means that a brute force scale up is not possible. That no viable alternative has yet been fully demonstrated shows the problem is a difficult one. We do not report a full solution, but we do show that the two technologies we are pursing have great promise. The basic underlying approach to both technologies is to use some replication process that copies the surface finish (length scales of less than 100 microns) of the master. Due to residual stresses in the replica, however, the macro figure needs to be corrected. We report here our work to develop two complementary technologies for which we have made advances that bring us close to being able to make "super Chandra" a reality. One technology is a spatially modulated bias coating process whose local stress changes the macro figure of the replica. The second process is to apply a magnetic smart material to the replica and to affect shape changes via the insertion of a magnetic field of strength order 0.1 T. Preliminary results indicate that both processes can reduce order 10-20 arc second figure errors to the 1 arc-second range. The finest length scale we have accomplished so far has been with the magnetic smart material. The length scale over which we produced a significant deviation was about 2 mm. The sample we used was a 100 micron thick glass. The magnetic field strength was about 0.1 T. To be determined for both technologies are what 2-D control can be accomplished, what are the smallest length scales over which we can reliably affect the changes, and what is the stability of the final figure. Further details will be presented at the workshop.

Capabilities and Science Drivers for the X-ray Surveyor Mission

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Abstract

The X-ray Surveyor mission concept is designed to make dramatic increases in discovery space and science capabilities for X-ray astronomy. These would be accomplished through orders of magnitude improvements over Chandra in sensitivity, field of view for sub-arcsec imaging, effective area for grating spectroscopy, and by providing high spectral resolution capabilities for extended objects on 1-arcsec angular scales. An X-ray observatory with such capabilities, operating in concert with other major astronomical facilities of the 2020-2030's, is required to address and solve some of the greatest challenges in modern astrophysics. The X-ray Surveyor will shed light on the formation of supermassive black holes by being able to detect X-rays from these objects as they grow beyond their seed state in the first galaxies. Direct data on the nature and operating modes of feedback will be provided by characterizing hot gas in galaxies and groups on scales from the very near vicinity of the central black out to the virial radius. A new era in our understanding of the plasma physics effects on astrophysical scales will be opened, for example, by resolving the detailed structure of relativistic shocks in pulsar wind nebulae and the gas turbulence in galaxy clusters. The detailed structure of the Cosmic Web will be exposed for the first time by mapping X-ray emission from hot gas in its filaments. The outstanding capabilities of X-ray Surveyor will make it an indispensable research tool in nearly every area of astrophysics.

Science with the Cherenkov Telescope Array Observatory

Amanda Weinstein (Iowa State) for the CTA Consortium

Abstract

There is a strong scientific synergy between MeV gamma-ray astronomy and the science done by ground-based very high-energy (VHE; E> 100 GeV) gamma-ray observatories. The Cherenkov Telescope Array (CTA) is a planned next-generation VHE gamma-ray observatory that will once again revolutionize our knowledge of the gamma-ray sky between 30 GeV and 100 TeV. Also unprecedented is the fact that CTA will be operated as an open observatory with a strong guest observer program. We provide a brief overview of the CTA science program and explain CTA's design and capabilities with respect to previous VHE gamma-ray telescopes. The anticipated requirements for participation in the guest observer program and the different mechanisms by which interested observers will be able to access CTA data and propose observations with CTA will also be explained, along with the types of data and analysis tools that are expected to be made publicly available.

The X-ray Surveyor Concept

Martin C. Weisskopf (MSFC), Alexey Vikhlinin (SAO), Jessica Gaskin (MSFC), Harvey Tananbaum (SAO), S. Bandler (GSFC), M. Bautz (MIT), D. Burrows (PSU), A. Falcone (PSU), F. Harrison (California Institute of Technology), R. Heilmann (MIT), S. Heinz (University of Wisconsin), C.A. Kilbourne (GSFC), C. Kouveliotou (George Washington University), R. Kraft SAO), A. Kravtsov (University of Chicago), R. McEntaffer (University of Iowa), P. Natarajan (Yale University), S.L. O'Dell (MSFC), A. Ptak (GSFC), R. Petre (GSFC), B.D. Ramsey (MSFC), P. Reid (SAO), D. Schwartz (SAO), L. Townsley (PSU)

Abstract

Over the past 16 years, NASA's Chandra X-ray Observatory has provided an unparalleled means for exploring the high-energy universe with its half-arcsecond angular resolution. Chandra studies have deepened our understanding of galaxy clusters, active galactic nuclei, galaxies, supernova remnants, planets, and solar system objects addressing most, if not all, areas of current interest in astronomy and astrophysics. As we look beyond Chandra, it is clear that comparable or even better angular resolution with greatly increased photon throughput is essential to address even more demanding science questions, such as the formation and subsequent growth of black hole seeds at very high redshift; the emergence of the first galaxy groups; and details of feedback over a large range of scales from galaxies to galaxy clusters. Recently, NASA Marshall Space Flight Center, together with the Smithsonian Astrophysical Observatory, has initiated an informal concept study for such a mission now named the X-ray Surveyor. We describe the concept study which starts with a baseline payload consisting of a high resolution X-ray telescope and an instrument set which may include an X-ray calorimeter, a wide-field imager and a dispersive grating spectrometer and readout. The telescope would consist of highly nested thin shells, for which a number of technical approaches are currently under development, including adjustable X-ray optics, differential deposition, and modern polishing techniques applied to a variety of substrates. In many areas, the mission requirements would be no more stringent than those of Chandra, and the study takes advantage of similar studies for other large area missions carried out over the past two decades. The mission is scientifically compelling, technically feasible, and worthy of a high prioritization by the next National Academy of Sciences Decadal Survey for Astronomy and Astrophysics.

The Future of X-ray Timing: A Probe-class Mission

Colleen A. Wilson-Hodge (NASA/MSFC), Deepto Chakrabarty (MIT), Paul S. Ray (NRL) for the US LOFT team

Abstract

A probe-class X-ray timing mission (~2-50 keV) requires very large collecting area, high time resolution, good spectral resolution, broadband spectral coverage, highly flexible scheduling, and an ability to detect and respond promptly to time-critical targets of opportunity. It addresses science questions such as: What is the equation of state of ultra dense matter? What are the effects of strong gravity on matter spiraling into black holes? It would be optimized for sub-ms timing of bright Galactic X-ray sources including X-ray bursters, black hole binaries, and magnetars to study phenomena at the natural timescales of neutron star surfaces and black hole event horizons and to measure mass and spin of black holes. These measurements are synergistic to imaging and high-resolution spectroscopy instruments, addressing much smaller distance scales than are possible without very long baseline X-ray interferometry, and using complementary techniques to address the geometry and dynamics of emission regions. This timing mission would have an effective area of 3-5 m^2, 5-8 times that of the highly successful Rossi X-ray Timing Explorer (RXTE). A sky monitor (~2-30 keV) acts as a trigger for pointed observations, providing high duty cycle, high time resolution monitoring of the X-ray sky with ~20 times the sensitivity of the RXTE All-Sky Monitor, enabling multi-wavelength and multi-messenger studies. A probe-class mission concept would employ lightweight collimator technology and large-area solid-state detectors, segmented into pixels or strips, technologies which have been recently greatly advanced for the proposed medium class ESA mission, the Large Observatory for X-ray Timing (LOFT). Since the ESA decision is expected soon, if LOFT is not selected we will discuss science drivers and trades for a probe-class mission in collaboration with the LOFT team; if LOFT is selected, we will discuss US involvement in LOFT and the importance of community support. Given the large community interested in LOFT (http://www.isdc.unige.ch/loft/index.php/loft-team/community-members), the scientific productivity of either X-ray timing mission is expected to be very high, similar to or greater than RXTE (~2000 refereed publications.)

High-sensitivity, Multi-band, All-sky Monitors for X-ray and Gamma-ray Sources

Kent S. Wood, J. Eric Grove, C. C. (Teddy) Cheung (Naval Research Laboratory), Peter F. Michelson (Stanford University), and Neil Gehrels (NASA GSFC)

Abstract

The Fermi LAT is a unique example of a high-sensitivity, imaging, all-sky monitor. It covers the entire sky (4pi sr) for source variability and transient activity to such a deep level that, when variability is detected, the discovery instrument itself provides the highest quality observations (temporal and spectral) available in its own (GeV to TeV) band. This is in contrast to the prevailing model whereby a monitor discovers activity, then hands off follow-up to other instruments that must be coordinated, subsequent to the trigger provided by the monitor. Most variable high-energy sources call for supporting observations in other wavelengths ranging from radio to TeV. Because of monitoring limitations, the coverage achieved often falls considerably short of ideal. Building on current concepts for imaging X-ray all-sky monitors plus recent and planned optical surveys, we describe a greatly improved time-domain astronomy mission that emulates Fermi by delivering simultaneous deep monitoring in the GeV (gamma-ray), keV (X-ray) and eV (optical) bands, i.e., over about 12 orders of magnitude in photon energy. We characterize the science that could be supported and explore technology and mission architecture issues in achieving such capability. Alternative realizations of this concept are described, including flagship class, probe class, and other approaches. This poster is only introductory; a near-term study of how to accomplish this objective is needed as part of preparations for the next Decadal Review.

Simulating, Calibrating, and Assessing the Performance of the next High-Energy Space Mission with MEGAlib

Andreas Zoglauer (University of California at Berkeley).

Abstract

The Medium-Energy Gamma-ray Astronomy library, MEGAlib, is a set of software tools for simulating, calibrating, and analyzing (measurements and simulations) of hard X-ray and gamma-ray instruments used for space (astrophysics, solar physics) and terrestrial applications (nuclear medicine, environmental monitoring).
The library comprises all necessary data analysis steps starting with Geant4 simulations or real detector measurements via detector calibration, Compton scattering & pair creation event reconstruction to image reconstruction and other high-level analysis tasks. MEGAlib has a completely object-oriented design and is written in C++. It is based on ROOT and Geant4.

MEGAlib has been designed from the ground up to be applied to a wide range of detector systems (scintillators, Anger cameras, strip and pixel semi-conductors detectors, etc.) including their individual detector effects, and to be applied to a wide range of different observation scenarios. As consequence, MEGAlib has been applied to past (e.g. COMPTEL, MEGA, NCT), existing (COSI, GRIPS, NuSTAR as well as HEMI and many other environmental monitoring systems), and envisioned space projects (e.g. ACT, GRI, GRIPS/MPE, ACT, DUAL, AstroMeV, AstroGAM, GRX) where it was used to determine the expected performance in the space radiation environment.

In the presentation we will give an overview of the general capabilities of MEGAlib with an emphasis on the latest additions of MEGAlib and its application to evaluate the performance of future high- energy space missions.

Exploring the gamma-ray sky with GRX and COSI

Andreas Zoglauer (University of California at Berkeley) and Steven E. Boggs (UCB) for the GRX & COSI collaborations.

Abstract

The Gamma-Ray Explorer, GRX, is an envisioned space-borne compact Compton telescope operating in the energy range from ~150 keV to 5 MeV. Its detector system consists of an array of 2x2x4 high-purity Germanium double-sided strip detectors (7.6 x 7.6 x 1.5 cm3, 128 orthogonal strips with 0.58 mm pitch). The GRX concept is based on the balloon-borne Compton telescope COSI (COmpton Spectrometer and Imager), formerly known as NCT – the Nuclear Compton Telescope. Combined they had 3 successful stratospheric balloon flights (2005, 2009, 2014). GRX' wide field-of-view (90 degrees FWHM), broad energy range (~150 keV to ~5 MeV for Compton imaging, down to ~40 keV for GRB and solar flare spectroscopy), excellent energy (~2.5 keV FWHM) and position (~0.3 mm3) resolution, its compact design (low amount of passive material in the detector head), its optimized orbit (equatorial LEO), as well as the resulting superior background suppression, good imaging resolution (2 degree @ 1809 keV), and good polarization sensitivity, make it an ideal instrument for wide-field imaging studies, high-resolution spectroscopy, and pioneering polarization observations. Its main scientific goals include to probe the origins of the positrons in our Galaxy, to gain new insights into how the elements are created by observing the tracers of nucleosynthesis in our Galaxy (e.g. 26-Al, 60-Fe, 44-Ti), to explore the most extreme environments in our Universe by performing pioneering studies of gamma-ray polarization in GRBs, black holes, and pulsars, and to further our understanding of supernovae, cosmic-rays, solar flares, and more. The balloon-borne COSI has similar scientific goals, but on a smaller scale due to the limitations of observing within the Earth's atmosphere (higher background, absorption, smaller field-of- view, and shorter duration). COSI's next flight is planned for 2016.

Simulating Astro-H Observations of Galaxy Cluster Gas Motions: What We Can Expect and Implications for Future Missions

John ZuHone (MIT Kavli Institute)

Abstract

The Astro-H satellite, with its high-spectral resolution X-ray calorimeter, will be the first instrument to be capable of elucidating the velocity structure of galaxy cluster plasmas via measurements of the shift and width of spectral lines. A number of interesting nearby clusters have been proposed as targets for the mission, including objects undergoing major mergers, turbulence, and "sloshing" motions. I will present predictions from hydrodynamical simulations for the effects of gas motions on the shift and shape of spectral lines, and the ability of Astro-H to discern the properties of the underlying velocity field. We employ synthetic observations of the X-ray emission from our simulated clusters to yield realistic Astro-H images and spectra which take into account the effects of the instrumental responses, vignetting, and PSF scattering. Our results show that Astro-H will reveal interesting details about the velocity field of nearby clusters, including constraining the injection scale of turbulence, and details of the sloshing motions seen in many cool-core clusters. However, the main factor limiting the science will be spatial resolution. To close, I will discuss what science may be achieved by future missions with similarly high spectroscopic resolution combined with high spatial resolution.