The power of X-ray spectroscopy

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Book of Abstracts

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AGN Jets as probes of relativistic thermodynamics (or: How hot are relativistic jets?)

Dr. ANTONUCCIO-DELOGU, Vincenzo[1]

[1] *INAF, Catania Astrophysical Observatory, ITALY*

Corresponding Author(s): vincenzo.antonuccio@oact.inaf.it

AGNs jets are often observed to be highly relativistic, and current models of their production from accretion discs also predict that near their production sites they could reach high values of the Lorentz boost factor γ. When jets interact with the material contained in their host galaxies (e.g. stars and their coronae, cold clouds, the diffuse warm ISM) they can excite high energy (soft- and hard X) spectral lines, whose properties depend crucially on the thermodynamical processes and modelling. Relativistic Thermodynamics (herafter RT) is however still a not firmly consolidated field, with many open questions (see e.g. Przanowski and Tosiek, Phys. Scripta 84, 055008 (2011) for a review), also connected to the relativistic transformation of fundamental intensive quantities like temperature. We have applied a recently developed approach based on the Redefined Relativistic Thermodynamics (RRT, Gonzales-Narvaez et al., Annals of Physics) to develop a physically motivated model of jet-cloud and jet-coronae interactions. We consider consider two main diagnostics: line ratios of highly ionised lines and charge transfer X-ray lines. We demonstrate that they are sensitive to the relativistic transformation of temperature (either the Ott-Rohrlich or Planck-Einstein laws), and can thus be used as probes of one of the most elusive open questions left in Relativity. Charge transfer reactions can explain some observed features of nearby SyII emission lines, as they can be produced during jet-cold clouds interactions. Finally, we also consider the thermodynamic implications of jet's \emph{backflows} (see e.g. Cielo, et al., MNRAS 467, 4526, 2017 for a recent review), and show that during the initial and the later *self-similar* phases they can approximately realise a *relativistic Carnot Cycle* with the hotspot and the Supermassive Back holes acting as heat reservoirs.

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Constraints on the Geometry of the Obscuring Torus from the NuSTAR Survey of the Local Seyfert II Population

Dr. BALOKOVIC, Mislav[1]

[1] *Harvard/SAO*

Corresponding Author(s): mislav.balokovic@gmail.com

The obscuring torus is one of the main components of the basic unified model of active galactic nuclei (AGN), needed to create anisotropy in obscuration as a function of the viewing angle. I will present the first study of the geometrical properties of the AGN torus in a large and representative sample of type II Seyfert nuclei. The sample consists of more than 120 AGN selected in the hard X-ray band from the Swift/BAT 70-month catalog and observed simultaneously with NuSTAR and Swift/XRT. These data enable us to explore the constraints that observed spectra place on the properties of the obscuring torus in individual AGN and in the local population of Seyfert II nuclei. We used empirically motivated spectral models for X-ray reprocessing in approximately toroidal geometry for constraining the distribution of the average column density of the torus, and the distribution of the torus covering factor within this sample. We find that the torus-averaged column density is independent of the line-of-sight column density, with typical column density that is borderline Compton-thick, i.e., around the unity optical depth for Compton scattering. The distribution of torus covering factors is broad but shows a preference for high covering, peaking around the covering factor of 90%, with the median at 70%, in agreement with recent sample studies in the infrared band. We also examined the dependence of the covering factor on intrinsic luminosity, finding that the median covering factor peaks around the intrinsic X-ray luminosity of 10ˆ42.5 erg/s and decreases toward both lower and higher luminosities.

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The Athena X-ray Integral Field Unit (X-IFU)

Author(s): Dr. BARRET, Didier[1]
Co-author(s): Dr. DEN HERDER, Jan-Willem [2] ; Dr. PIRO, Luigi [3] ; Mr. LAM-TRONG, Thien [4] ; Dr. CAPPI, Massimo [5]

[1] *IRAP/CNRS*

[2] *SRON*

[3] *IAP/INAF*

[4] *CNES*

[5] *IASF*

Corresponding Author(s): dbarret@irap.omp.eu

Athena is the second large mission of the ESA Cosmic Vision program to probe the hot and energetic Universe, and as a multi-purpose observatory, to enable a wide range of astrophysical sources to be investigated. Athena will carry a large aperture X-ray telescope, with two interchangeable focal plane instruments: a wide field imager and a high resolution X-ray spectrometer, namely the X-ray Integral Field Unit (X-IFU). The X-IFU will deliver spatially resolved spectra with a 2.5 eV spectral resolution, on 5 arc second pixel size, over a field of view of 5 arc minutes (equivalent diameter) and in the 0.2 to 12 keV range. In this paper, I will review the Athena science objectives driving the X-IFU performance requirements, and describe the status of the X-IFU including its anticipated performance, as it approaches the end of its feasibility study phase.

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Disc truncation in the hard state of GX 339-4 and Cygnus X-1

Author(s): Dr. BASAK, Rupal[1]
Co-author(s): Prof. ZDZIARSKI, Andrzej [2] ; Dr. PARKER, Michael [3] ; Dr. ISLAM, Nazma [4]

[1] *KTH Royal Institute of Technology*

[2] *N. Copernicus Astronomical Center*

[3] *University of Cambridge*

[4] *Centrum Astronomiczne im. Mikolaja Kopernika PAN*

Corresponding Author(s): rupal.basak@gmail.com

The accretion disc geometry in the hard state of X-ray binaries (XRB) is a hotly debated topic. For many years, observations in the hard state has been successfully explained by a truncated disc with a hot inner flow geometry, while the soft state has a disc extending down to innermost stable circular orbit (ISCO). Some recent studies find a disc extending very close to the ISCO even in the hard state. These claims are based on an extreme broadening of iron line complex in the reflected spectrum due to high relativistic effects close to the black hole. Then, some other studies show that some of these data are affected by pile-up that leads to the broadening. Here, we present a detailed spectral analysis of two back hole XRBs namely, GX 339-4 and Cyg X-1 in the hard state. For the former we use high resolution XMM-Newton data simultaneously fitting all the observations in 2–10 keV, while for the later we use simultaneous Suzaku and Nustar data covering a wider band, 1–250 keV. We use a number of models for the continuum and reflection. Our best-fit models show that the disc is indeed truncated at several gravitational radii. A part of the line broadening is due to ionization parameter and the assumption of the underlying continuum. Then the relativistic effects further broaden the line but with moderate effects. In the lamppost model, though a disc down to ISCO is possible, the source height is far from the horizon which again has a moderate relativistic effect.

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Changes in the pulse phase dependence of X-ray emission lines in 4U 1626-67 with a torque reversal

Author(s): Dr. BERI, ARU[1]
Co-author(s): Prof. PAUL, Biswajit [2] ; Dr. GULAB, Dewangan [3]

[1] *University of Southampton*

[2] *Raman Research Institute, Bangalore*

[3] *Inter-University Centre for Astronomy & Astrophysics (IUCAA)*

Corresponding Author(s): a.beri@soton.ac.uk

We will present results from a new observation with the XMM-Newton observatory of a unique X-ray pulsar 4U 1626-67. Epic-pn data during the current spin-up phase of 4U 1626-67 have been used to study pulse phase dependence of low energy emission lines. We found strong variability of low energy emission lines with the pulse phase varying by a factor of 2-10, much stronger than the continuum variability. Another interesting observation is that behavior of low energy emission lines across the pulse phase is quite different from that observed during the spin-down phase. This indicates that the structures in the accretion disk that produce pulse phase dependence of emission features have changed from spin-down to spin-up phase. An additional new difference found from this observation is that below 2 keV, the X-ray pulse profile in the spin-up phase is quite different compared to the spin-down phase. The X-ray light curve also shows flares which produce a feature around 3˜mHz in power density spectrum of 4U 1626-67.

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Radiation Pressure Confinement in the X-ray Narrow Line Region of NGC1068

Prof. BIANCHI, Stefano[1]

[1] *Università degli Studi Roma Tre*

Corresponding Author(s): bianchi@fis.uniroma3.it

Radiation pressure in Active Galactic Nuclei gives rise to a pressure gradient in any illuminated photoionized gas with ionization parameter $\xi \gg 1$. It was shown that this pressure gradient, known as radiation pressure confinement (RPC), has distinctive implications that appear to be observed over a large range of distances from the nucleus and gas densities. In particular, the spatial overlap between the X-ray and the optical Narrow Line Region (NLR) is nicely predicted by RPC. We present here preliminary results of RPC models applied to the exceptional XMM-Newton RGS soft X-ray spectrum of the Compton-thick AGN, NGC1068. To our knowledge, this is the first attempt to model the ionization distribution of the gas producing the X-ray line emission in the NLR.

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X-ray spectra of tetrahedral nanodiamonds

Author(s): Prof. BILALBEGOVIC, Goranka[1]
Co-author(s): Dr. MAKSIMOVIC, Aleksandar [2]

[1] *University of Zagreb, Faculty of Science, Department of Physics*

[2] *Center of Excellence for Advanced Materials and Sensing Devices, Rudjer Boskovic Institute, Bijenicka cesta 54, 10000 Zagreb, Croatia*

Corresponding Author(s): goranka.bilalbegovic@gmail.com

The existence of diamond nanoparticles close to the Herbig Ae/Be stars Elias 1 and HD 97048 was proposed from their infrared spectra. IR intensities of astrophysical spectra correspond to those measured for large tetrahedral nanodiamonds. Elias 1 and HD 97048 are known as sources of X-ray emission. Using density functional theory methods we calculate X-ray spectra of two tetrahedral nanodiamonds: C26H32 and C51H52. We also study and test our methods on methane for which extensive X-rays laboratory data are available.

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Arcus: The X-ray Grating Spectrometer Explorer

Dr. BRENNEMAN, Laura[1]

[1] *Smithsonian Astrophysical Observatory*

Corresponding Author(s): lbrenneman@cfa.harvard.edu

Arcus is a NASA/MIDEX mission under development in response to the 2016 call for proposals. It is a free-flying, soft X-ray grating spectrometer with the highest-ever spectral resolution in the 12-50 Å (0.25 – 1.03 keV) energy range. The *Arcus* bandpass includes the most sensitive tracers of diffuse million-degree gas: spectral lines from O VII and O VIII, H- and He-like lines of C, N, Ne and Mg, and unique density- and temperature-sensitive lines from Si and Fe ions. These capabilities enable an advance in our understanding of the formation and evolution of baryons in the Universe that is unachievable with any other present or planned observatory. The mission will address multiple key questions posed in the Decadal Survey and NASA's 2013 Roadmap: How do baryons cycle in and out of galaxies? How do black holes and stars influence their surroundings and the cosmic web via feedback? How do stars, circumstellar disks and exoplanet atmospheres form and evolve? *Arcus* data will answer these questions by leveraging recent developments in CAT gratings and silicon pore optics to measure X-ray spectra at high resolution from a wide range of sources within and beyond the Milky Way. CCDs with strong *Suzaku* heritage combined with electronics based on the *Swift* mission will detect the dispersed X-rays. *Arcus* will support a broad astrophysical research program, and its superior resolution and sensitivity in soft X-rays will complement the forthcoming *Athena* calorimeter, which will have comparably high resolution above 2 keV.

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Molecular clouds and a supermassive black hole in our Galactic Center

Dr. CHURAZOV, Eugene[1]

[1] *MPA, IKI*

Corresponding Author(s): churazov@gmail.com

While the supermassive black hole Sgr A*at the center of the Milky Way is currently very dim, we believe that it experienced a powerful outburst of X-ray radiation hundreds of years ago. The historical record of this outburst is revealed by reflection/reprocessed radiation coming from dense molecular clouds. The imprints left by the outburst in spatial and time variations of the reflected emission suggest that the outburst happened some hundred years ago. It lasted less than several years and Sgr A* was more than million times brighter than today. These characteristics are consistent with a relatively modest tidal disruption event. Thus, molecular clouds offer us a convenient tool to study Sgr A*'s past history. At the same time, the outburst serves as an extremely powerful probe of molecular gas. Essentially, this is the only opportunity to reconstruct a full 3D structure of molecular clouds and their density PDF. Future X-ray observatories, including cryogenic bolometers and polarimeters, will further boost our ability to conduct in-depth studies of molecular gas and outbursts of Sgr A*.*

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Astrophysical Dust Mineralogy with X-ray Spectroscopy

Author(s): Dr. CORRALES, Lia[1]
Co-author(s): Prof. WILMS, Joern [2] ; Dr. GARCIA, Javier [3] ; Dr. GATUZZ, Efrain [4]

[1] *University of Wisconsin - Madison*

[2] *University of Erlangen*

[3] *Caltech / U. Erlangen*

[4] *Max Planck Institute for Astrophysics*

Corresponding Author(s): lia@astro.wisc.edu

A significant fraction of the heavy elements produced by stars enters the interstellar medium in the form of dust grains. These grains serve as heavy metal transports, influence gas cooling

during star formation, and eventually become the seeds for planet formation. Much like quasar spectra are used to probe intergalactic gas, observations of X-ray bright compact objects can yield key insights to the mineralogy and evolution of dust grains in the Milky Way. X-ray light is sufficient to excite electrons from the n=1 (K-shell) and n=2 (L-shell) energy levels of neutral interstellar metals, causing a sharp increase in the absorption cross-section. Near the ionization energy, the shape of the photoelectric absorption edge depends strongly on whether the atom is isolated or bound in molecules or minerals (dust). With high resolution X-ray spectroscopy, we can directly measure the state of metals and the mineral composition of dust in the interstellar medium. In addition, the scattering contribution to the X-ray extinction cross-section can be used to gauge grain size, shape, and filling factor. This type of study requires large effective area and high spectral resolution at softer energies, which is more easily achieved with gratings instruments.

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The strange case of the ionized gas in the Seyfert galaxy IZw1

Dr. COSTANTINI, Elisa[1]

[1] *SRON Netherlands Institute for Space Research*

Corresponding Author(s): e.costantini@sron.nl

We present a simultaneous spectroscopy campaign using XMM-Newton and HST-COS on the bright narrow-line Seyfert 1 IZw1. This source already displayed peculiar behavior in past observations (Costantini et al. 2007), showing a multi-component UV-Xray warm absorber in apparent constant non-equilibrium and a variable iron K alpha line (Gallo et al. 2007).
Our recent campaign casts a new light on the warm absorber behavior, showing a clear link between the low-, the high- ionization and the UV gas components as well as a variable column density (Silva, Costantini et al. to be subm.).
These observational elements clearly challenge the classical conical-shaped outflow in ionization equilibrium, favoring e.g. episodes of gas ejection, possibly from the accretion disk. These unique results highlight the need of high-quality, multi-wavelengths observations for understanding the outflows mechanisms.

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Accretion disc winds

Dr. DIAZ TRIGO, Maria[1]

[1] *ESO*

Corresponding Author(s): mdiaztri@eso.org

Accretion onto neutron stars and black holes powers the most luminous phenomena in the Universe. Associated to it is the existence of outflows, in the form of uncollimated winds or highly collimated relativistic jets. The origin of outflows and their feedback to the environment is one of the most debated topics in astrophysics today. In this talk I will review the current understanding of accretion disc winds in X-ray binaries, their launching mechanism and their relation to specific accretion states. I will also discuss the potential interplay between the appearance/disappearance of such winds and relativistic jets and the insight gained with ongoing multi-wavelength observational programmes focused on the variability of such phenomena.

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Do thermal-radiative winds in Galactic binary systems explain everything?

Prof. DONE, Chris[1]

[1] *University of Durham*

Corresponding Author(s): chris.done@durham.ac.uk

I will review the theory of thermal winds, and show how this can make quantitative predictions for the column and ionisation state along the line of sight. I will show how these can explain all of the observations of winds in binaries so far, with quantitative comparisons to the Chandra high resolution data, including the apparent switch off of the high/soft state wind as the source makes a transition to the low/hard state. This behaviour is predicted by the thermal wind models and does not require the magnetic field to switch between powering the wind to powering the jet. Radiation pressure should be important as the source approaches Eddington, giving composite thermal-radiative winds, and I show how these may explain the huge wind seen in an apparently low luminosity state of GRO1655-40. The successes of these physically understood wind models mean there is little room left for magnetic winds in binary systems. I suggest that the same may be true in AGN also.

Corona/disk interaction – modelling / 61

High-Resolution Reflection Spectroscopy of Accreting Compact Objects

Dr. GARCIA, Javier[1]

[1] *Caltech*

Corresponding Author(s): javier@caltech.edu

The X-ray emission from accreting compact objects (e.g., black holes and neutron stars) is often accompanied by a reflection spectrum, which shows signatures of energetic photons being reprocessed by the optically thick material within the accretion disk. Given their abundance and fluorescence yield, K-shell lines from iron are the most prominent in the X-ray reflected spectrum. These and other spectral profiles can be grossly broadened and skewed due to Doppler effects and gravitational redshift, which take place near the compact object. Consequently, by modeling the reflection spectrum it is possible to learn about the disk composition, ionization state, and dynamics. Moreover, reflection spectroscopy is currently one of the best means to estimate the spin of black holes, and more recently the properties of the corona that produces the X-ray emission. In this talk I will review the most important theoretical and observational aspects of reflection spectroscopy, with emphasis on its applicability to stellar-mass black holes and neutron stars in binary accreting systems, as well as to supermassive black holes in active galactic nuclei. I will discuss outstanding issues in the field, and the prospects to new high-resolution and large collecting area missions.

Diffuse emission from Milky Way and ISM / 50

The Milky Way's gas: An X-ray perspective

Author(s): Dr. GATUZZ, Efrain[1]
Co-author(s): Dr. GARCIA, Javier [2] ; Dr. KALLMAN, Timothy R. [3] ; Dr. CHURAZOV, Eugene [1]

[1] *Max-Planck Institute for Astrophysics*

[2] *CALTECH*

[3] *NASA/GSFC*

Corresponding Author(s): egatuzz@mpa-garching.mpg.de

High resolution X-ray spectroscopy is a powerful technique for studying the physical conditions in the interstellar medium (ISM). Using a bright X-ray source as a background lamp we can analyze the absorption features that are imprinted in the spectra by the gas located in the line of sight between the source and the observer. In this way we can estimate abundances, column densities, ionization fractions as well as kinematic propierties of the multiple ions identified. I will summarize our knowledge regarding the cold, warm and hot gas in the Milky Way as observed through X-ray absorption analysis with an emphasis on the importance of the atomic data and the future perspectives.

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X-raying stellar winds in high mass X-ray binaries

Dr. GRINBERG, Victoria[1]

[1] *ESA/ESTEC*

Corresponding Author(s): vgrinberg@cosmos.esa.int

We are made of stardust-or, at least in significant parts, of material processed in stars. Hot, massive giant stars can drive the chemical evolution of galaxies and trigger and quench star formation through their strong winds and their final demise as supernovae. Yet, optical and X-ray measurements of the wind mass loss strongly disagree and can only be reconciled if the winds are highly structured, with colder, dense clumps embedded in a tenuous hot gas. But in (quasi-)single stars wind properties are inferred for the whole clump ensemble. No measurements of individual clumps or clump groups are possible. Luckily, nature provides us with perfect laboratories to study clumpy winds: high mass X-ray binaries (HMXBs), systems where a neutron star or a black hole accretes matter from the wind of an giant stellar companion and emits the so freed energy mainly in the X-ray band. This radiation is quasi-pointlike and effectively X-rays the wind, in particular the clumps crossing the line of sight towards the neutron star or black hole. High resolution spectra are crucial for understanding such winds, giving information on structure, temperature profiles and shape of clumps. I will particularly show how we use observations obtained with Chandra-HETG and XMM-RGS to constrain wind properties of the two of the brightest high mass X-ray binaries, Cyg X-1 and Vela X-1, and how future instruments such as XARM and Athena will allow us to probe individual clumps.

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High-resolution spectroscopy in the Athena era

Dr. GUAINAZZI, Matteo[1]

[1] *European Space Agency*

Corresponding Author(s): matteo.guainazzi@sciops.esa.int

In this talk I will present the scientific objectives and the Study status of Athena - the Advanced Telescope for High-ENergy Astrophysics. Athena was selected in June 2014 as the second L-class mission in ESA's Cosmic Vision 2015-25 plan, with a launch foreseen in 2028. It is an X-ray observatory designed to address the two questions of Cosmic Vision science theme 'The Hot and Energetic Universe': a) How does ordinary matter assemble into the large-scale structures we see today? and; b) How do black holes grow and shape the Universe? It will achieve these goals by studying a wide range of astrophysical phenomena: the formation and evolution of groups and clusters of galaxies; the chemical evolution of hot baryons; feedback effects of active galactic nuclei; missing baryons thought to populate the intergalactic medium; the formation and early growth of black holes; and the accretion by super-massive black holes through cosmic time, among others. These goals will be achieved through an unprecedented combination of an X-ray telescope with a focal length of 12 m and an effective area of ˜1.4-2 square meters at 1 keV, and two instruments: an X-ray Integral Field Unit (X-IFU) for spatially-resolved, high spectral resolution (˜2.5 eV) imaging spectroscopy over a ˜5'x5' field-of-view, and a Wide Field Imager (WFI) for high count rate, moderate resolution spectroscopy over a large field of view (˜40'x40'). In this talk I will focus on the role that high-resolution spectroscopic observations, coupled with an unprecedented combination of effective area and spatial resolution (the X-IFU pixel size ˜5", comparable to the HEW of the telescope PSF) will play in addressing the aforementioned science topics. The mission is currently in the study phase ("Phase A") aiming at the scientifically optimal design. Upon completion, Athena will be proposed for 'adoption' around 2020, thus leading to the start of the construction phase.

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X-ray/UV connection and the nature of accretion disks in Seyferts

Author(s): Dr. GULAB, Dewangan[1]
Co-author(s): Mr. PAWAR, Pramod [2] ; Dr. PAL, Main [3] ; Ms. MALLICK, Labani [4]

[1] *Inter-University Centre for Astronomy & Astrophysics (IUCAA)*

[2] *SRTM University, Nanded*

[3] *PRL, Ahmedabad*

[4] *IUCAA, Pune*

Corresponding Author(s): gulabd@iucaa.in

The origin of optical/UV continuum emission and the nature of accretion disks in Seyfert nuclei have been a puzzle. The optical/UV continuum is thought to arise from accretion disks but the nature of disks in AGN, assumed to be the standard Shakura-Sunyaev disks, is not well understood. Using XMM-Newton, Swift and AstroSat observations of Seyfert type AGN, we have performed detailed study of the optical-to-X-ray continuum and the correlation between optical/UV and X-rays. Our results include (i) lack of connection between the hot corona and the intermediate regions in the disk, (ii) larger disk sizes than predicted by the standard disk model, and (iii) the evidence for UV photons acting as the seed for thermal Comptonization.

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The Livermore EBIT laboratory astrophysics program in a new era of atomic physics data needs

Author(s): Dr. HELL, Natalie[1]
Co-author(s): Dr. BROWN, Greg [1] ; Dr. BEIERSDORFER, Peter [1] ; Dr. LOCKARD, Tom [1] ; Dr. KELLEY, Richard L. [2] ; Dr. KILBOURNE, Caroline A. [2] ; Dr. LEUTENEGGER, Maurice A. [2] ; Dr. PORTER, F. Scott [2] ; Dr. WILMS, Joern [3]

[1] *LLNL*

[2] *NASA GSFC*

[3] *Dr. Remeis-Sternwarte & ECAP, FAU*

Corresponding Author(s): natalie.hell@fau.de

Recently, observations with the Hitomi microcalorimeter Soft X-ray Spectrometer (SXS) have highlighted open issues of currently available plasma models and their underlying atomic physics databases. In preparation for future X-ray micro calorimeter missions, such as XARM or Athena, improvements to these models and databases play an integral role in ensuring our ability to take full advantage of the diagnostic power that spectra from these missions have been shown to deliver. Benchmark and reference atomic data measured in a well understood, controlled laboratory environment are essential to reach this goal. The Livermore electron beam ion trap EBIT-I, in conjunction with a suit of high-resolution spectrometers, such as crystal spectrometers and the EBIT Calorimeter Spectrometer (ECS) with similar properties to the SXS, is ideally suited to provide such measurements. In this overview, we will describe how our EBIT measurements provide reference data with accuracies fulfilling current and future requirements on the atomic data. For example, the accuracy for energies of K-shell transitions in L-shell ions of Si and S as measured with the ECS exceeds the calibration accuracy of the Chandra HETG, while measurements with a spherical crystal spectrometer have accuracies corresponding to Doppler shifts smaller than 30km/s, exceeding the requirements set by the Athena observatory. In addition, our measurements of absolute collisional excitation cross sections for K-shell transitions in highly-charged Fe and Fe-group elements currently have accuracies on the ~10% level, in line with pre-Hitomi requirements, with new efforts allowing to push these uncertainties to a few percent.
Work was performed under auspices of U.S. D.o.E. by LLNL under contract DE-AC52-07NA27344 and supported by NASA grants to LLNL and GSFC.

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Chandra Studies of the Collisionally-Ionized Plasma in the Ultracompact X-ray Binary 4U 1626-67

Author(s): Dr. HEMPHILL, Paul[1]
Co-author(s): Dr. SCHULZ, Norbert [1] ; Prof. CHAKRABARTY, Deepto [1]

[1] *MIT*

Corresponding Author(s): pbh@space.mit.edu

I present an analysis of Chandra/LETGS and Chandra/HETGS observations of the ultracompact X-ray binary 4U 1626−67. This system hosts a neutron star accreting from a white dwarf companion, is one of the most compact in its class, with an orbital period of 41 minutes. The neutron star is also a pulsar with a period of 7.7 s and a magnetic field of around 4×10^{12} Gauss. A recent Chandra/HETGS study identified a collisional plasma as the origin for strong Ne and O diskline emission, which led to a determination of a source inclination of 38 degrees, suggesting a carbon/oxygen composition for the white dwarf donor. The Chandra/LETGS observations were designed to identify emission from H- and He-like carbon in order to verify the expectation that the accreted plasma is mostly composed of carbon and oxygen, and allow us to establish a low temperature limit for the collisionally ionized plasma. The previously reported detection of a narrow Fe line also provides a challenge to interpretations of the nature of the system, as this line was detected in observations in 2010 and 2015, but not in 2014. We will discuss our findings in the context of the origins of the collisional ionized plasma as well as the nature of the Fe K line emission.

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Winds of Massive Stars: Line Profiles and Variability

Author(s): Dr. HUENEMOERDER, David[1]
Co-author(s): Dr. WALDRON, Wayne [2] ; Dr. NICHOLS, Joy [3] ; Dr. NAZE, Yael [4]

[1] *MIT*

[2] *Eureka Scientific*

[3] *Smithsonian Astrophysical Observatory*

[4] *Univ. de Liege*

Corresponding Author(s): dph@space.mit.edu

The X-ray line profiles from the winds of massive stars are determined by the wind structure and dynamics. Stellar winds, however, are not necessarily uniform or constant, as is seen in features migrating through UV and optical lines, interpreted as co-rotating interaction regions (CIR). We have searched for line variability in the O-star, zeta Puppis (among others), with suggestive but unconvincing results. With greater sensitivity and high spectral resolution, we would be able to determine if there are X-ray counterparts to CIR and refine our understanding of plasma heating in winds and the use of X-ray emission lines as diagnostics of mass loss.

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Hitomi SXS view of the gas motions in the core of the Perseus cluster

Dr. ICHINOHE, Yuto[1]

[1] *Tokyo Metropolitan University*

Corresponding Author(s): ichinohe@tmu.ac.jp

We present the results associated with gas motions in the core of the Perseus galaxy cluster observed with the Hitomi soft X-ray spectrometer (SXS). We searched for spatial variations in the bulk velocity as well as the line-of-sight (LOS) velocity dispersion of the ICM in the Perseus cluster out to 100 kpc from its center. Some advanced topics including the investigation of the shapes of major emission lines and the measurements the ICM ion temperature are also reported.

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Orbital resolved spectroscopy of GX 301-2: wind diagnostics

Author(s): Dr. ISLAM, Nazma[1]
Co-author(s): Prof. PAUL, Biswajit [2]

[1] *Centrum Astronomiczne im. Mikolaja Kopernika PAN*

[2] *Raman Research Institute, India*

Corresponding Author(s): nislam@camk.edu.pl

GX 301-2, a bright high-mass X-ray binary with an orbital period of 41.5 days, exhibits stable periodic orbital intensity modulations with a strong pre-periastron X-ray flare. Several models have been proposed to explain the accretion at different orbital phases, invoking accretion via stellar wind, equatorial disc, and accretion stream from the companion star. From the orbital resolved spectroscopic study of GX 301–2 with the X-ray all sky monitor MAXI, we found a very large equivalent width of the iron line for a small value of the column density in the orbital phase range 0.10–0.30 after the periastron passage. The orbital dependence of the spectral parameters favours accretion on to the neutron star occurring via a high density accretion stream plus stellar wind of the companion. We further investigate the characteristics of the accretion stream with an ASTROSAT SXT+LAXPC observation of the system.

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Stability of radiation pressure dominated accretion disks

Prof. JANIUK, Agnieszka[1]

[1] *Center for Theoretical Physics*

Corresponding Author(s): agnieszka.janiuk@gmail.com

The thermal instability of accretion disks and the induced limit-cycle oscillations strongly depend on the ability of the plasma to cool down. Several factors may play a role in this aspect, e.g., wind outflows, viscous fluctuations, advection, opacity functions. The results of local and global numerical simulations presented by various groups lead to different conclusions. On the other hand, observations of several black hole X-ray binaries, intermediate mass black hole, and some AGN, suggest directly or indirectly, that the 'heartbeat' states are realized in nature. In this talk I will review the current theoretical and observational status of black hole accretion disk instabilities.

AGN nature and their winds / 46

An Overview of X-ray Reverberation Mapping

Dr. KARA, Erin[1]

[1] *University of Maryland*

Corresponding Author(s): ekara@astro.umd.edu

Active Galactic Nuclei can produce as much or more electromagnetic and kinetic luminosities than the combined stellar luminosity of an entire galaxy. Though the masses of the central black holes are typically 500-1000 times less their host galaxies, AGN appear to play a vital role in regulating the growth of the most massive galaxies. The energy output from AGN comes from the gravitational potential energy of the infalling material and the rotational energy of the black hole. In both cases, most of the energy is released very close to the black hole, and therefore, probing the relativistic region of the inner accretion flow is essential to understanding how AGN work and effect their environments. In this review, I will focus on a new technique, X-ray reverberation mapping, which allows us to map the gas falling on to the black hole and measure the effects of strongly curved spacetime close to the event horizon.

AGN nature and their winds / 70

Fe K-alpha Profiles from Simulations of Accreting Black Holes

Author(s): Mr. KINCH, Brooks[1]
Co-author(s): Dr. SCHNITTMAN, Jeremy [2] ; Dr. KALLMAN, Timothy [2] ; Dr. KROLIK, Julian [1]

[1] *Johns Hopkins University*

[2] *NASA Goddard Space Flight Center*

Corresponding Author(s): bkinch1@jhu.edu

We present a new technique for the prediction of Fe Kα profiles directly from general relativistic magnetohydrodynamic (GRMHD) simulations. Data from a GRMHD simulation are processed by a Monte Carlo global radiation transport code, which determines the X-ray flux irradiating the disk surface and the coronal electron temperature self-consistently. With that irradiating flux and the disk's density structure drawn from the simulation, we determine the radiation field within the accretion disk from photoionization equilibrium and solution of the radiative transfer equation, including all relevant physical processes—this is accomplished via a new disk reprocessing code, PTRANSX, in conjunction with XSTAR. This yields an outgoing spectrum at each point on the disk surface including the Fe Kα photons, which are then ray-traced to an observer at infinity to produce a line template ready for observational comparison; for the 10 $M_\odot$ case we have examined already, both the shapes of the line profiles and the equivalent widths of our predicted Kα lines are qualitatively similar to those typically observed from accreting black holes. Most importantly, this technique allows for the translation of state-of-the-art global simulation data into readily observable spectral data, allowing for more direct comparison between theory and observation.

Corona/disk interaction – modelling / 43

Disk/corona physics - implications for X-ray spectroscopy

Dr. LIU, Bifang[1]

[1] *National Astronomical Observatories, Chinese Academy of Sciences*

Corresponding Author(s): bfliu@nao.cas.cn

I'll briefly review disk/corona models around a black hole, then introduce the disk/corona interaction model from low mass X-ray binaries to AGNs, discussing the difference in the hard X-ray spectrum between binaries and AGNs. The geometry of the accretion flows in the proximity of black hole, the radiation compactness, and their dependence on Eddington ratio are presented. Implications for the X-ray spectroscopy, such as the reflection and reverberation lags, are discussed.

AGN nature and their winds / 60

X-ray Winds in AGN

Dr. LONGINOTTI, Anna Lia[1]

[1] *CONACYT- INAOE (Instituto Nacional de Astrofisica Optica y Electronica)*

Corresponding Author(s): annalia@inaoep.mx

This talk will give an overview of recent results on AGN outflows, with a particular focus on grating spectra of bright sources. I will describe what X-ray spectra tell us about the properties of slow winds (warm absorbers) and I will review our current knowledge of ultra fast winds, discuss what is their impact on the host galaxies and address how high-resolution spectroscopy is the optimal tool to explore this phenomenon.

AGN nature and their winds / 15

Origin of the soft X-ray excess and nature of broadband X-ray variability in the bare Seyfert 1 galaxy Ark 120

Author(s): Ms. MALLICK, LABANI[1]
Co-author(s): Dr. GULAB, Dewangan [2]

[1] *The Inter-University Centre for Astronomy and Astrophysics*

[2] *Inter-University Centre for Astronomy & Astrophysics (IUCAA)*

Corresponding Author(s): labani@iucaa.in

Abstract We present results of a long \sim500 ks XMM-Newton observation of a bare Seyfert 1 galaxy Ark 120 which showed diminution and increment in the 0.3-10 keV X-ray flux alternatively over four consecutive orbits during 2014 March. Here we investigate the origin of the soft X-ray excess emission and broadband X-ray variability through time-averaged X-ray spectroscopy, root mean squared (rms) spectral modelling and UV/X-ray correlation. The X-ray (0.3-10 keV) spectra are well fitted by a thermally Comptonized primary continuum with two (blurred and distant) reflection components and an optically thick, warm Comptonization component for the soft X-ray excess emission below \sim2 keV. During the first and third observations, the X-ray rms spectrum shows a decrease in variability with energy while for second and fourth observations, X-ray variability spectra are found to be inverted-crescent and crescent shaped, respectively. All four X-ray rms variability spectra are well modelled by a soft excess component with variable luminosity and a variable primary emission with the normalization and photon index being correlated. The spectral hardening of the source with both the UV and soft X-ray luminosities favour Comptonization models where the soft excess and primary X-ray emissions are produced through Compton up-scattering of the UV and UV/soft X-ray seed photons in the warm and hot coronae, respectively. Our broadband spectral-timing analyses suggest that the observed energy-dependent X-ray variability of Ark 120 is likely to be the result of variations in the spectral shape and intrinsic luminosity of the hot coronal emission as well as the luminosity of the soft excess emitting warm corona and is mainly driven by variations in the Comptonizing seed photons.

AGN nature and their winds / 36

Obscured AGN studied with X-ray spectroscopy

Prof. MATT, Giorgio[1]

[1] *Universita' Roma Tre*

Corresponding Author(s): matt@fis.uniroma3.it

X-ray obscured AGN are ideal sources to study circumnuclear regions, because the emission from these regions is not diluted by the nuclear radiation. Much information is encoded in emission lines, and especially in the iron K lines, and medium resolution (i.e. CCD-like) spectroscopy has already provided very important results on the physical and geometrical properties of circumnuclear matter. The advent of high resolution spectroscopy with XARM and ATHENA will provide the next leap forward, allowing to also study the dynamical properties.

AGN nature and their winds / 56

Chasing obscuration in type-I AGN: discovery of an eclipsing clumpy wind in NGC 3783

Author(s): Dr. MEHDIPOUR, Missagh[1]
Co-author(s): Prof. KAASTRA, Jelle [1] ; Dr. KRISS, Gerard [2]

[1] *SRON*

[2] *Space Telescope Science Institute*

Corresponding Author(s): m.mehdipour@sron.nl

In 2016 we carried out a Swift monitoring program to track the X-ray hardness variability of eight type-I AGN over a year. The purpose of this monitoring was to find intense obscuration events in AGN, and thereby study them by triggering joint XMM-Newton, NuSTAR, and HST observations. We successfully accomplished this for NGC 3783 in December 2016. We found heavy X-ray absorption produced by an obscuring outflow in this AGN. As a result of this obscuration, interesting absorption features appear in the UV and X-ray spectra, which are not present in the previous epochs. Namely, the obscuration produces broad and blue-shifted UV absorption lines of Ly-alpha, C IV, and N V, together with a new high-ionisation component producing Fe XXV and Fe XXVI absorption lines. In soft X-rays, only narrow emission lines stand out above the diminished continuum as they are not absorbed by the obscurer. Our analysis shows that the obscurer partially covers the central source with a column density of few 10^{23} cm^{-2} outflowing with a velocity of few thousand km/s. The obscuration in NGC 3783 is variable and lasts for about a month. Unlike the commonly-seen warm-absorber winds at pc-scale distances from the black hole, the eclipsing wind in NGC 3783 is located at ~10 light days. Our results suggest the obscuration is produced by an inhomogeneous and clumpy medium, consistent with clouds in the base of a radiatively-driven disk wind at the outer broad-line region of the AGN.

SNR and stars / 3

Mysterious short-lived emission lines in nova ejecta of RS Oph

Author(s): Dr. NESS, Jan-Uwe[1]
Co-author(s): Dr. ORIO, Marina [2] ; Dr. BEHAR, Ehud [3]

[1] *ESA*

[2] *INAF-Padova and University of Wisconsin*

[3] *Technion, Israel Institute of Technology*

Corresponding Author(s): juness@sciops.esa.int

The recurrent symbiotic nova RS Oph was intensely observed in X-rays during its 6th known outburst in 2006. Around 30 days after outburst, atmospheric X-ray emission from the white dwarf emerged in the form of a bright, soft spectrum, also known as Super Soft Source spectrum. A few days before, XMM-Newton took a 10-ks observation in order to observe cooling shocks that occurred between nova ejecta and stellar wind of the companion star. While the shock emission remained constant during the observation, the soft light curve experienced a sudden increase by a factor 6. In the EPIC spectrum, this increase was accompanied by a new soft component that can well be fit with a black body model. The simultaneous high-resolution RGS spectrum, however, is extremely complex with emission lines that can to date not be identified. We show the time evolution of the RGS spectrum, demonstrating that the unidentified lines lived only for a short time. We further discuss our failed attempts to identify them and ways forward to understand where atomic physics need to be improved and what was actually happening during this observation. This is a good example of the need for high-resolution spectroscopy as pursued by Athena.

Corona/disk interaction – modelling / 57

GR effects in black-hole accreting flows

NIEDZWIECKI, Andrzej[1]

[1] *Lodz University*

Corresponding Author(s): niedzwiecki@uni.lodz.pl

I will discuss GR effects in the observed properties of the X-ray radiation produced close to the black hole horizon. Many published results give the X-ray source location within a few gravitational radii from the horizon; however, they are based on fitting the relativistic reflection model which does not properly implement the gravitational energy shifts, furthermore, they use the reflection amplitude which is not physically related with the radial emissivity. I will illustrate the related inaccuracies by comparing those results with fits using our newly developed xspec model. I will also discuss GR effects affecting the radiative efficiency and the pair-production stability of the X-ray source located very close to the horizon.

AGN feedback and Clusters / 24

Probing hot gas velocity field in massive galaxies and galaxy clusters with resonant scattering in the era of high resolution X-ray spectroscopy

Author(s): OGORZALEK, Anna[1]
Co-author(s): Dr. ZHURAVLEVA, Irina [1] ; Prof. ALLEN, Steven [1] ; Dr. PINTO, Ciro [2] ; Prof. WERNER, Norbert [3] ; Dr. MANTZ, Adam [1] ; Dr. CANNING, Rebecca [1] ; Prof. FABIAN, Andrew [4] ; Prof. KAASTRA, Jelle [5] ; Dr. DE PLAA, Jelle [5]

[1] *Stanford University*

[2] *University of Cambridge, Institute of Astronomy*

[3] *MTA-Eotvos University*

[4] *Cambridge University*

[5] *SRON*

Corresponding Author(s): ogoann@stanford.edu

Resonant scattering is a subtle process that suppresses fluxes of some of the brightest optically thick X-ray emission lines produced by collisional plasmas in galaxy clusters and massive early-type galaxies. The amplitude of the effect depends on the turbulent structure of the hot gas, making it a sensitive velocity probe, and, moreover, the primary method of constraining anisotropy of gas motions. It is therefore crucial to properly model this effect in order to correctly interpret current high resolution X-ray spectra of extended sources from XMM-Newton Reflection Grating Spectrometer (RGS) and Hitomi, as well as future ones from X-ray Astronomy Recovery Mission and Athena. In this talk I will show results of applying the resonant scattering method to probe velocities of hot gas motions in a sample giant elliptical galaxies with RGS and in the core of Perseus Cluster with Hitomi. I will also discuss the limitations, uncertainties, and future prospects of this approach.

Corona/disk interaction – modelling / 29

Broadband X-ray spectroscopic study of different spectral states and state transition during the onset of a giant radio flare in Cyg X-3 as observed by AstroSat

Author(s): Dr. PAHARI, MAYUKH[1]
Co-author(s): Prof. MISRA, RANJEEV [1] ; Dr. CHANDRA, SUNIL [2] ; Prof. YADAV, J S [2]

[1] *IUCAA*

[2] *TIFR*

Corresponding Author(s): mayukh@iucaa.in

Due to the wind-fed accretion from a high mass Wolf-Rayet companion star and very compact binary orbit (~8.4 hours), the broadband X-ray spectra of Cyg X-3 is notoriously complex. On the other hand, the source uniquely shows giant radio flare of the order of ~20 Jy although the nature of the compact object is unknown. This is why we need to study the long-term, systematic behavior of Cyg X-3 both in X-ray and Radio. AstroSat frequently monitors Cyg X-3 during last one, and half year and interestingly such monitoring program cover all spectral states reported in the literature. In one of the observations, AstroSat closely monitors the formation of a giant radio jet base and found a new spectral state which was anticipated previously but not observed. A flat X-ray powerlaw extended upto 80 keV is clearly observed in this state. Synchrotron emission from the radio jet is the only possible origin of such powerlaw. In this talk, I shall summarize results from the broadband X-ray spectroscopic study of Cyg X-3 in 0.3-80 keV and discuss the properties of the new spectral state and X-ray behavior of the source on hour time scale during the onset of a giant radio flare.

AGN nature and their winds / 6

New frontiers in ultra-fast outflow spectroscopy

Dr. PARKER, Michael[1]

[1] *University of Cambridge*

Corresponding Author(s): mlparker@ast.cam.ac.uk

The discovery of multiple rapidly variable absorption features from an ultra-fast outflow (UFO) in the most X-ray variable galaxy, IRAS 13224-3809, has opened a new window for us to study AGN outflows and feedback. When combined with the sensitivity and resolution of ATHENA it will be possible to reverberation-map these outflows for the first time, detecting the spectro-timing signatures of both the emission and absorption components of these outflows. This will allow us to measure in detail the geometry of the UFOs, which is essential for understanding the physics of how they are launched and accelerated, and their impact on AGN feedback. I will discuss the recent results on IRAS 13224, which make it the ideal source for taking the next steps in understanding UFOs, and explore how ATHENA and other next-generation telescopes will revolutionise the study of these outflows.

AGN nature and their winds / 0

(Non-)variability in the NGC 7469 X-rays spectrum

Mr. PERETZ, Uria[1]

[1] *Technion*

Corresponding Author(s): uperetz@tx.technion.ac.il

This presentation will describe the campaign on NGC 7469 aimed at determining the physical parameters of the ionized outflows associated with it, in order to better understand galactic feedback of AGNs to their host galaxies. We measure column densities of the ionized outflow using an individual-ion based approach and compare different epochs, to accurately determine variability on scales of years, months, and days. Three velocity components are measured with this method, -600, -990, and -2000 km s^{-1}. We find no significant variability, implying the outflow is a large distance from the source. The implied lower bound on the ionization time, 10 years, constrains the distance to be at least a few pc, and more likely at a few 10s of pc. The ionization distribution (AMD) is reconstructed from measured column densities, nicely matching results of 2004 observations, with one large high-ionization component at 2-3 log ξ, and perhaps one more at 0.5 log ξ. The kinetic power of the outflow is constrained to be less than source luminosity, suggesting negligible if any contribution to galactic feedback.

Winds in XRB, ULX, GRB / 7

Powerful outflows in Ultraluminous X-ray sources

Dr. PINTO, Ciro[1]

[1] *University of Cambridge, Institute of Astronomy*

Corresponding Author(s): cpinto@ast.cam.ac.uk

The detection of fully-grown supermassive black holes powering active galactic nuclei at high redshift, when the Universe was young, challenges the theories of black holes growth, requiring long periods of high accretion, most likely above the Eddington limit. This is a focus of the next generation large missions, but cannot be done with the current instrumentation due to the large distances. Therefore, we need to study objects accreting at high rates in the nearby Universe. Most ultraluminous X-ray sources (ULXs, luminosities $> 3 \cdot 10^{39}$ erg/s) show X-ray spectra that are consistent with stellar mass black holes or neutron stars accreting at or above Eddington and provide the best workbench to study super-Eddington accretion and fast growth rates. A few, exceptionally bright, ULXs are good candidates for hosting intermediate mass black holes (e.g. 1000 solar masses), which are thought to be necessary seeds for the formation of supermassive black holes. In this talk I will discuss our recent important discoveries that shook this research field in support for super-Eddington accretion: the detection of relativistic outflows in several archetypal ULXs in the form of resolved X-ray spectral lines. I will also show our first constraints on masses, accretion rates, and feedback.

X-ray binary – winds / 65

Disk Winds – comparison between XRBs and AGN

Dr. PONTI, Gabriele[1]

[1] *Max-Planck-Institut fuer Extraterrestrische Physik*

Corresponding Author(s): ponti@mpe.mpg.de

X-ray binary – winds / 66

Disc winds in X-ray binaries

Dr. PONTI, Gabriele[1]

[1] *Max-Planck-Institut fuer Extraterrestrische Physik*

Corresponding Author(s): ponti@mpe.mpg.de

The advent of the new generation of X-ray telescopes yielded a significant step forward in our understanding of ionised absorption generated in the accretion discs of X-ray binaries. It has become evident that these relatively weak and narrow absorption features, sporadically present in the X-ray spectra of some systems, are actually the signature of equatorial outflows, which might carry away more matter than that being accreted. Therefore, they play a major role in the accretion phenomenon. These outflows are ubiquitous during the softer states but absent during the powerlaw dominated, hard states, suggesting a strong link with the state of the inner accretion disc and the spectral energy distribution of the illuminating source. I will review the current understanding of the field and discuss possible connections to winds in AGN.

Instruments and future / 1

AstroSat contributions to X-ray spectroscopy

Author(s): Prof. RAO, A Raghu[1]
Co-author(s): Dr. GULAB, Dewangan [2]

[1] *Tata Institute of Fundamental Research*

[2] *Inter-University Centre for Astronomy & Astrophysics (IUCAA)*

Corresponding Author(s): a.raghu.rao@gmail.com

AstroSat is a multi wavelength astronomical observatory launched in September 2015. The Soft X-ray Telescope (SXT) of AstroSat provides medium resolution X-ray spectroscopy (about 140 eV at 6 keV) for a variety of astrophysical sources. The strength of AstroSat, however, is the use of co-aligned wide band instruments used in conjunction with SXT: the Large Area X-ray Proportional Counter (LAXPC) and Cadmium Zinc Telluride Imager (CZTI). The combined data is very useful to pin down the X-ray continuum spectra in a very wide band of 0.2 keV - 150 keV. Some recent results on nearby AGN and Galactic Black Hole binaries will be presented which demonstrate the usefulness of measuring the continuum to understand the soft X-ray line spectra of astrophysical sources.

AGN nature and their winds / 37

Radiation Pressure and the Absorption Measure Distribution

Author(s): Prof. ROZANSKA, Agata[1]
Co-author(s): Mr. ADHIKARI, Tek Prasad [2] ; Dr. HRYNIEWICZ, Krzysztof [1]

[1] *CAMK PAN*

[2] *NICOLAUS COPERNICUS ASTRONOMICAL CENTER OF THE POLISH ACADEMY OF SCIENCES*

Corresponding Author(s): agata@camk.edu.pl

Absorption measure distribution in AGN can be determined since we are able to see absorption lines on highly ionised elements with CHANDRA/XMM-Newton precision. AMD is best tool to measure the global distribution of this warm gas which interacts with radiation coming from the nucleus. The observed deeps in AMD are well explained by the eventual thermal instability in caused by strong gas irradiation with hard X-rays. I will present how the distribution of absorbed gas depends on gas physical parameters and what has the biggest influence on the location of observed deeps and AMD normalisation. I will discuss the best warm absorber model which explains the observed AMD shape in currently available sources.

AGN feedback and Clusters / 54

X-ray emission from galaxy clusters

Dr. SANDERS, Jeremy[1]

[1] *Max Planck Institute for Extraterrestrial Physics (MPE)*

Corresponding Author(s): jsanders@mpe.mpg.de

X-ray spectroscopy allows us to measure the physical properties of the intracluster medium, the dominant baryonic component of galaxy clusters. Density can be computed from the emission measure, while the temperature and metallicity of the intracluster medium can be obtained from the shape of the spectrum and the strength of its emission lines. With sufficient spectral resolution, velocities of the gas can also be measured. I will show results from a recent Chandra analysis of the Centaurus cluster of galaxies, where we used spatially-resolved X-ray spectroscopy to observe the processes of cooling and AGN feedback. I will show how deep data also allow us to map the distribution of metals in the intracluster medium. I will discuss recent work where XMM and Hitomi were used to put constraints on the motions in the intracluster medium. I will briefly show how Athena will greatly improve our understanding of these systems.

Diffuse emission from Milky Way and ISM / 20

Measuring the Dust and Gas Phases towards the Galactic Bulge

Author(s): Dr. SCHULZ, Norbert[1]
Co-author(s): Mrs. CORRALES, Lia [2] ; Prof. CANIZARES, Claude [1]

[1] *MIT*

[2] *University of Wisconsin*

Corresponding Author(s): nss@space.mit.edu

Since its emergence, high resolution X-ray spectroscopy has made a decisive impact on the study of properties of the gas phases in the interstellar medium (ISM). Resolving the O K, Fe L, and Ne K edge structures not only helped us understand how X-ray spectra are affected by absorption, but also exposed the physics of the cold, warm and ionized as well as hot phases of the ISM. And while some studies identified signatures related to dust and molecular components, their existence remained inconclusive. In contrast, studies of higher Z edges such as Mg K, Si K and S K clearly indicate dominant dust signatures in the edge structure. In a recent survey of the Si K edge in X-ray binaries located in the Galactic Bulge of the Milky Way we describe the edge using several components which include multiple edge functions, near edge absorption excesses from silicates in dust form, contributions from X-ray scattering optical depths as well a the precence of a variable warm absorber from atomic silicon. New data of GX 3+1 offer a very deep view of the Si K edge and many more details. Some of the details require spectral resolutions of better than 5 eV and can only be deciphered using high energy grating (HEG) data. The ultra-resolved edge structures in Si K and now likely also in Mg K allow us to directly determine the gas to dust ratio in the ISM towards the Galactic Bulge. We present current results and discuss them in the context of ISM properties and star formation rates.

SNR and stars / 12

The power of X-ray spectroscopy to probe the jets and environments of gamma-ray burst afterglows

Dr. STARLING, Rhaana[1]

[1] *University of Leicester*

Corresponding Author(s): rlcs1@le.ac.uk

95%*of Swift-triggered gamma-ray bursts have a detected X-ray afterglow, dominated by synchrotron emission created at shock fronts where the jet interacts with the surrounding medium. Despite having more than a thousand afterglows in hand, the diversity among them continues to challenge emission models which must accurately describe jet structure, time evolution of shock fronts, environmental and line-of-sight density profiles, and the existence in some cases of as yet unexplained periods of sustained emission, thermal components and giant flares. In this talk I will review the role of X-ray spectroscopy in probing GRB afterglows, and then focus in on recent work on thermal X-ray components and ultra-long GRBs.*e.g. Evans et al. (2009)

AGN nature and their winds / 5

X-ray observations of ultrafast outflows and their implication for AGN feedback

Dr. TOMBESI, Francesco[1]

[1] *University of Rome Tor Vergata / NASA-GSFC / University of Maryland*

Corresponding Author(s): francesco.tombesi@gmail.com

Powerful winds driven by active galactic nuclei (AGN) are often invoked to play a fundamental role in the evolution of both supermassive black holes (SMBHs) and their host galaxies, affecting star formation and driving the tight SMBH-galaxy relations. Strong support for this mode of AGN feedback came from recent X-ray spectroscopic observations of mildly relativistic disk winds in some ultra-luminous infrared galaxies and their connection with large-scale molecular outflows observed in other wavelengths, suggesting a direct link between the SMBH and the gas out of which stars form. Systematic X-ray spectroscopic analyses of highly ionized Fe K absorption lines suggest that such ultrafast outflows (UFOs) may be common in local AGN and quasars. However, their origin and characteristics are still not fully understood. Revolutionary improvements in this field are expected from the unprecedented spectroscopic and imaging capabilities of the Athena X-ray observatory in synergy with upcoming major space- and ground-based facilities at other wavelengths.

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Heating versus cooling in the moderate redshift galaxy clusters 3C 444 and ZwCl 2701

Author(s): Dr. VAGSHETTE, Nilkanth[1]
Co-author(s): Prof. PATIL, Madhav [2] ; Dr. NAIK, Sachindra [3]

[1] *M.U. College, Udgir*

[2] *S R T M University, Nanded*

[3] *Physical Research Laboratory, Ahemadabad*

Corresponding Author(s): nilkanth1384@gmail.com

We present results obtained from the analysis of high resolution Chandra data on 3C 444 and ZwCl 2701 galaxy clusters. These clusters are located at redshifts of 0.153 and 0.214, respectively, each hosting a pair of X-ray cavities. A comparison of the surface bright distribution of the X-ray emitting plasma and the diffuse radio emission revealed a good spatial association in both the systems. The detected X-ray cavities allowed us to quantify the mechanical power that has been injected by the central AGN and utilized for heating the surrounding gas. The total estimated powers in these systems were found to be $\sim$6.3 $\times$ 10^{44} erg s^{-1} and 2.27 $\times$ 10^{45} erg s^{-1}, respectively, with cavity ages about $10^7 - 10^8$ yr. The measured X-ray luminosity within the cooling radius ($\sim$100 kpc) is found to be much smaller than the mechanical power, implying that the injected power is capable enough to compensate the radiative loss. Temperature and density profiles derived from the spatially resolved spectral analysis of the X-ray emission from 3C 444 exhibited presences of a rarely detected elliptical shock surrounding the X-ray cavities. A shock has also been detected in the other system ZwCl 2701. Using the observed density jumps in these system at shock locations, the computed Mach numbers are found to lie between 1.25 – 1.72.

Corona/disk interaction – modelling / 9

Investigating state transition luminosities of Black Hole X-ray Binaries in the outburst decay

Author(s): Mr. VAHDAT MOTLAGH, Armin[1]
Co-author(s): Dr. KALEMCI, Emrah [2]

[1] *Istanbul Technical University*

[2] *Sabanci University*

Corresponding Author(s): mv.armin@gmail.com

In the outburst cycle of black hole X-ray binaries, the transition from hard to soft state occurs at higher luminosity compared to soft to the hard state. In this study we performed spectral and timing analyses in order to obtain the luminosity distribution of BHXBs in the outburst decay. By exploring the key parameters of state transition we aimed to investigate the origin of hysteresis in the hardness-intensity diagram as well as investigating the variability of state transition luminosities for multiple sources in the outburst decay. The transition luminosities were found for abrupt changes in spectral and timing properties (using definitions in Kalemci et al 2013 and Belloni et al 2010). The analyses were done for 12 BH transient in 20 outburst decays, and for disk and power-law luminosities separately. Our results show a tight clustering in bolometric corrected power-law luminosity around 3% Eddington Luminosity when sources make a final transition to the hard state as the power-law photon index reaches a constant value, extending earlier work of Maccarone et al. in 2003. We discuss the reasons for clustering and possible explanations for sources that show a transition luminosity below the general trend.

Diffuse emission from Milky Way and ISM / 58

X-ray Spectroscopy and Interstellar Dust

VALENCIC, Lynne[1]

[1] *Johns Hopkins University*

Corresponding Author(s): lynne.a.valencic@nasa.gov

X-ray spectroscopy is a crucial tool in studies of the interstellar medium, and interstellar dust in particular, in that it can provide direct measurements of elemental abundances and grain compositions, thus allowing us to build more realistic grain models. Athena's X-IFU instrument, with its unprecented high resolution, will allow us to examine aspects of dust that have remained hidden until now. I will discuss Athena's potential for shedding light on some of the more pressing questions in interstellar dust studies.

AGN feedback and Clusters / 32

Clusters of galaxies and the chemical enrichment of the intergalactic medium

Dr. WERNER, Norbert[1]

[1] *MTA-Eotvos University/Masaryk University/Hiroshima University*

Corresponding Author(s): wernernorbi@gmail.com

Galaxy clusters are unique astrophysical laboratories which allow us to study nucleosynthesis and the chemical enrichment history of the Universe. The deep gravitational potential wells of galaxy clusters hold all of the metals ever produced by stars in member galaxies, making them archaeological treasure troves to study the integrated history of star formation. The dominant fraction of the metals in clusters currently resides within the hot intra-cluster medium, where their abundances can be measured accurately via X-ray spectroscopy. I will review the observational constraints on the history of the chemical enrichment of the intergalactic medium and on the supernovae which dominated the enrichment. I will also discuss the implications of the recent results for the feasibility of mapping the warm hot intergalactic medium permeating the filamentary cosmic web via high resolution X-ray spectroscopy.

SNR and stars / 14

X-rays from supernova remnants: now and future

Dr. YAMAGUCHI, Hiroya[1]

[1] *NASA/GSFC*

Corresponding Author(s): hiroya.yamaguchi@nasa.gov

X-ray observations of supernova remnants (SNRs) offer crucial information about the progenitor's explosion and the interaction between the ejecta and ambient medium. An X-ray-emitting plasma in SNRs is commonly in non-equilibrium ionization (NEI), where the ionization degrees of heavy elements are lower (or sometimes higher) than those expected for an equilibrium plasma with a certain electron temperature. Under such condition, collisional interactions between hot electrons and low-ionized heavy elements produce innershell ionization, followed by fluorescence transitions. I will demonstrate how these fluorescence lines are important for plasma diagnostics in astrophysics, based on CCD observations of young SNRs. Unfortunately, recent Hitomi observations of several SNRs were not successfully done, so we were not able to obtain high-resolution spectra from NEI plasma. I will therefore discuss the prospects for future studies with X-ray Astronomy Recovery Mission (XARM) and Athena, based on some simulations as well as results from grating observations.

AGN nature and their winds / 55

AGN feedback in an isolated elliptical galaxy

Prof. YUAN, Feng[1]

[1] *Shanghai Astronomical Observatory*

Corresponding Author(s): fyuan@shao.ac.cn

AGN feedback is beleived to play an important role for galaxy evolution. Using high-resolution 2D HD numerical simulation, we study the feedback effect of the AGN on the cosmological simulation of an isolated elliptical galaxy. The inner boundary of the simulation domain is small enough so that the Bondi radius of accretion is resolved. Special attention will be paid to using correct feedback physics, which is found affect the results significantly.

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Donut strikes sandwich: the geometry of the hard state in accreting black-hole binaries

Author(s): Mr. ZDZIARSKI, Andrzej[1]
Co-author(s): Mrs. VELEDINA, Alexandra [2] ; Prof. POUTANEN, Juri [2]

[1] *N. Copernicus Astronomical Center*

[2] *University of Turku*

Corresponding Author(s): aaz@camk.edu.pl

We study implications of the mutual interaction of a hot plasma and cold medium in black-hole binaries in their hard spectral state on the value of the truncation radii of accretion discs. We consider a number of different geometries. Different than previous theoretical studies, we use

a state-of-the art, energy-conserving, code for reflection and reprocessing from cold media. We show that a static corona above a disc extending to the innermost stable circular orbit produces spectra not compatible with those observed. They are either too soft or require the disc ionization much higher than that observed. This conclusion confirms a number of previous findings but disproves a recent study claiming an agreement of that model with observations. We show that the cold disc has to be truncated in order to agree with the observed spectral hardness. Still, a cold disc truncated at a large radius and replaced by a hot flow produces spectra which are too hard if the only seed photons for Comptonization are those from the disc. Our favourable geometry is a truncated disc coexisting with a hot plasma either overlapping with the disc or containing some cold matter within it.