Astrophysics of hot plasma in extended X-ray sources

12−14 June 2019
European Space Astronomy Centre (ESAC)
Villafranca del Castillo
Madrid, Spain

A conference organised by the European Space Agency
XMM-Newton Science Operations Centre

ABSTRACT BOOK

Oral Communications and Posters

Edited by

Jan-Uwe Ness

Organising Committees

Scientific Organising Committee

Monique Arnaud	Commissariat á l'énergie atomique Saclay, Gif sur Yvette, France
Aya Bamba	University of Tokyo, Japan
Hans Boehringer	Luwig-Maximilians-Universitaet Muenchen, Germany
Joel N. Bregman	University of Michigan, Ann Arbor, USA
Anne Decourchelle (chair)	Commissariat á l'énergie atomique Saclay, Gif sur Yvette, France
Andy Fabian	University of Cambridge, United Kingdom
Jimmy Irwin	University of Alabama, Tuscaloosa, USA
Jelle Kaastra	Netherlands Institute for Space Research, Utrecht, The Netherlands
Rosine Lallement	Observatoire de Paris, Meudon, France
Pasquale Mazzotta	Università di Roma "Tor Vergata", Italy
Takaya Ohashi	Tokyo Metropolitan University, Japan
Paul Plucinsky	Harvard-Smithsonian Center for Astrophysics, Cambridge, USA
John Raymond	Harvard-Smithsonian Center for Astrophysics, Cambridge, USA
Thomas Reiprich	Bonn University, Germany
Samar Safi-Harb	University of Manitoba, Winnipeg, Canada
Norbert Schartel (co-chair)	European Space Agency, Villanueva de la Cañada, Spain
Aurora Simionescu	Netherlands Institute for Space Research, Utrecht, The Netherlands
Randall Smith	Harvard-Smithsonian Center for Astrophysics, Cambridge, USA
Regis Terrier	Université Paris Diderot, France
Jacco Vink	University of Amsterdam, The Netherlands
Q. Daniel Wang	University of Massachusetts, Amherst, USA

Local Organising Committee (XMM-Newton Science Operations Centre)

Simone Migliari (Chair)
Lucia Ballo
Ignacio de la Calle
Jacobo Ebrero
Felix Fürst
Cristina Hernandez
Aitor Ibarra
Jan-Uwe Ness
Richard Saxton
Norbert Schartel
Michael Smith
Ana Willis
Ivan Valtchanov

Contents

Chapter 1

Invited Speakers

The Athena X-ray observatory

Didier Barret[1], Anne Decourchelle[2], Matteo Guainazzi[3], Jan-Willem den Herder[4], Andrew Fabian[5], Hironori Matsumoto[6], Kirpal Nandra[7], Luigi Piro[8], Randall Smith[9], Richard Willingale[10]
[1]*Institut de Recherche en Astrophysique et Planétologie, Toulouse, France*
[2]*Commissariat à l'énergie atomique Saclay, Gif sur Yvette, France*
[3]*European Space Agency, Noordwijk, The Netherlands*
[4]*Netherlands Institute for Space Research, Utrecht, The Netherlands*
[5]*University of Cambridge, United Kingdom*
[6]*Department of Earth and Space Science, Graduate School of Science, Osaka University, Osaka, Japan*
[7]*Max-Planck-Institut für extraterrestrische Physik, Garching, Germany*
[8]*Institute for Space Astrophysics and Planetology, Roma, Italy*
[9]*Center for Astrophysics — Harvard & Smithsonian, Cambridge, USA*
[10]*University of Leicester, Leicester, United Kingdom*

The Advanced Telescope for High-Energy Astrophysics (Athena) will be the second large mission of the European Space Agency science program. It will combine a large area X-ray mirror and two focal plane switchable instruments: the wide field imager (WFI) and the X-ray Integral Field Unit (X-IFU). After recalling briefly its core science objectives and performance requirements, I will present the expectations of Athena for probing hot plasmas in a few selected cases of extended X-ray sources. I will then report on the status of the mission and its science payload with the latter having just completed the review of its feasibility.

Charge exchange, from the laboratory to the sky

Gabriele Betancourt-Martinez[1]
[1]*L'Institut de Recherche en Astrophysique et Planétologie, Toulouse, France*

Charge exchange (CX) is a conceptually simple but theoretically complex atomic process that leads to spectral line emission in the X-ray band, only discovered to be important in astronomy in the last few decades. It occurs in nearly any environment where hot plasma and cold gas interact: in the solar system, between solar wind ions and neutrals in comets and planetary atmospheres, and likely also astrophysically, in, for example, supernova remnants and galaxy clusters. CX models often do not accurately describe observations or laboratory measurements, however. This can lead to an improperly subtracted X-ray foreground, incorrect assumptions about the physical properties of our astrophysical targets, and missed opportunities to harness the diagnostic utility of CX. In this talk, I will discuss how CX can impact our observations from current (XMM, Chandra) and future (XRISM, Athena) missions, the successes and failures of current CX models, and how laboratory astrophysics is a critical component of an improved CX theory.

Cluster Outskirts: New Frontiers in Astrophysics and Cosmology

Esra Bulbul[1]
[1] *Center for Astrophysics — Harvard & Smithsonian*

Cluster outskirts, located at the intersection of extended filaments of baryons and dark matter, provide crucial information on the assembly and virialisation processes of massive dark matter haloes. Measuring the thermodynamic and kinematic properties of the intracluster medium in low-density regions of galaxy clusters is challenging and require deep observations with large etendue, throughput, and high energy-dispersive spectral resolution instruments. I will review the current state of the art observational constraints of cluster outskirts and provide future prospects with forthcoming planned X-ray and SZ observatories.

The cold interstellar medium seen in X-rays

Elisa Costantini[1], Sascha Zeegers[2], Daniele Rogantini[1], Cor de Vries[1], Ioanna Psaradaki[1]
[1] *SRON Netherlands Institute for Space Research*
[2] *ASIAA, Academia Sinica, Taiwan*

In this talk I will review the methods and the state of art of the study of interstellar dust as seen in the X-rays. In particular I will focus on the powerful diagnostics provided by the extinction features imprinted in the X-ray spectra of sources located in the galactic plane. These signatures of the dust grains, interacting with background X-rays, are able to reveal the chemical composition, and physical properties of the intervening dust. These studies are now supported by a set of our laboratory measurements, forming a data base of unprecedented completeness and accuracy. Finally I will illustrate our recent results on the dense ISM environments towards the galactic center, via the study and modeling of the Si and Mg K-edges in the X-ray band.

Modelling and simulations of supernova remnants

Gilles Ferrand[1,2]
[1] *Astrophysical Big Bang Laboratory (ABBL), RIKEN, Wakō, Japan*
[2] *Interdisciplinary Theoretical and Mathematical Sciences Program (iTHEMS), RIKEN, Wakō, Japan*

Supernova remnants (SNRs) are the outcome of supernovae (SNe, either core-collapse or thermonuclear). The remnant results from the interaction between the stellar ejecta and the ambient medium around the progenitor star. Young SNRs are characterized by strong shocks that heat and ionize the gas, generate (magneto-)hydrodynamic turbulence, and accelerate particles to relativistic energies. They radiate at all wavelengths, especially in the X-ray domain, where spectro-imaging observations can provide a wealth of information. In this talk I will present recent progress in the modelling of SNRs, particularly by the means of numerical simulations, and with a focus on three-dimensional aspects. In the first part we will consider SNRs as producers of cosmic rays (CRs). If SNRs are accelerators efficient enough to power the Galactic component of CRs, this must have a visible impact on their dynamics, and therefore on the thermal emission from the plasma, as well as on their non-thermal emission. In the second part we will consider SNRs as probes of the explosion mechanism. The time has come to connect simulations of SNe and simulations of SNRs, opening the possibility to study the explosion mechanism via the dynamics and morphology of SNRs.

APEC atomic rates

Adam Foster[1]
[1] *Center for Astrophysics — Harvard & Smithsonian, Cambridge, USA*

The AtomDB atomic database contains a range of fundamental atomic data for analyzing a range of astrophysical plasmas. These are then processed through the APEC code to produce line emissivities, which form the widely used "apec" model in tools such as XSPEC and ISIS.

For some important pieces of atomic data there are several, often conflicting, sources for the same data. Resolving this conflict is not trivial, as it can involve redefining the models to make use of it. We here discuss the atomic data contained within AtomDB, the changes which have been implemented in the past year, and the future plans for improvement. We also discuss the effects of some of the alternative choices not made with the atomic data.

Related to this, we also present a comparison suite developed for showing the differences between AtomDB data and other related atomic databases. These allow quantifying the effects of the different plasma modeling codes for some typical astrophysical plasmas, and can serve as a catch all for many atomic data changes.

X-ray view of the hot circum-galactic medium

Jiangtao Li[1]
[1] *Department of Astronomy, University of Michigan, Ann Arbor*

The hot circum-galactic medium (CGM) represents hot gas distributes beyond the stellar content of the galaxies while typically within their dark matter halos. It serves as a depository of energy and metal-enriched materials from galactic feedback and a reservoir from which the galaxy acquires fuels to form stars. It thus plays a critical role in the coevolution of galaxies and their environments. X-ray is one of the best ways to trace the hot CGM. In this talk, I will briefly review what we have learned about the hot CGM based on X-ray observations, especially over the past two decades via Chandra and XMM-Newton. I will also briefly prospect what may be the foreseeable breakthrough in the next one or two decades with future X-ray missions.

The Morphologies and Kinematics of Supernova Remnants

Laura Lopez[1]
[1] *The Ohio State University*

I will review the major advances in using the morphologies and kinematics of supernova remnants (SNRs) to probe their explosive origins, evolution, and interactions with their surroundings. Simulations of SN explosions have improved dramatically over the last few years, and SNRs can be used to test models through comparison of predictions with SNRs' observed large-scale compositional and morphological properties as well as the three-dimensional kinematics of ejecta material. In particular, Galactic and Magellanic Cloud SNRs offer an up-close view of the complexity of these events. I will summarize the progress tying SNRs to their progenitors' explosions through imaging and spectroscopic observations, and I will discuss exciting future prospects for SNR studies, such as X-ray microcalorimeters.

XRISM

Kyoko Matsushita[1]
[1] *Tokyo University of Science*

The X-ray Imaging and Spectroscopy Mission (XRISM) is a JAXA mission, with NASA and ESA participation. The objective is pioneering a new horizon of the Universe with unprecedented high resolution X-ray spectroscopy. The XRISM consists of two instruments: Resolve and Xtend. The detector of Resolve is a X-ray calorimeter, similar to the SXS onboard Hitomi, and that of Xtend is a CCD detector. In this talk, we would like to review the Hitomi science and status of the XRISM mission.

Chemical abundances in the hot atmospheres of galaxy clusters, groups, and elliptical galaxies

Francois Mernier[1,2,3]
[1] *MTA - Eötvös University Lendület Hot Universe Research Group, Budapest, Hungary*
[2] *Institute of Physics, Eötvös University, Budapest, Hungary*
[3] *SRON Netherlands Institute for Space Research, Utrecht, The Netherlands*

Whereas the extreme conditions of the first minutes after the Big Bang produced nearly all the hydrogen and helium in the Universe, the most common heavier elements – or metals – are synthesised in the core of stars and in supernova explosions. These metals, on the other hand, are found not only in galaxies but also the very hot and diffuse X-ray atmospheres pervading the large gravitational potential well of galaxy clusters, groups, and massive galaxies. The presence of these elements even at the largest scales of the Universe offers unique opportunities to understand (and compare) the chemical history of galaxies and galaxy groups/clusters.

In this talk, we will see how measuring the abundances of key-elements in the hot atmospheres of galaxy clusters, groups, and ellipticals observed with the current X-ray observatories helps to understand where, how, and at which epoch of the cosmic history the intracluster medium became chemically enriched. Finally, I will discuss how future Athena will push forward our understanding of the ICM enrichment.

Background modelling

Silvano Molendi[1]
[1]*IASF-Milano INAF*

Amongst the major objectives of future high spectral resolution X-ray experiments is the study of diffuse emission from low surface brightness sources. This will only be possible if the background contaminating the low surface brightness emission will be well understood and modeled. Since, as everybody knows after Hitomi, much information is contained the 7 keV Fe K-alpha line, instrumental background will play a particularly important role. The work that is being done to study the background follows 2 paths: detailed simulations of the expected background of future experiments and through study of background data from currently operating missions. In this presentation I will review some of the major findings of the last few years and sketch what we hope to achieve in the next.

Lessons learned from 19 years of high-resolution X-ray spectroscopy of galaxy clusters with RGS

Ciro Pinto[1], Andrew Fabian[2], Jeremy Sanders[3], Jelle de Plaa[4], Chris Bambic[2], Haonan Liu[2], Peter Kosec[2], Chris Reynolds[2], Helen Russell[2], Michael McDonald[5]
[1]*European Space Agency, Noordwijk, The Netherlands*
[2]*Institute of Astronomy, Cambridge, United Kingdom*
[3]*Max-Planck-Institut fur extraterrestrische Physik, Garching, Germany*
[4]*Netherlands Institute for Space Research, Utrecht, The Netherlands*
[5]*Kavli Institute for Astrophysics and Space Research, Cambridge, USA*

Galaxy clusters are the largest individual objects in our Universe and ideal laboratories to study plasma physics. The intracluster medium (ICM) contains the vast majority of the baryonic matter in galaxy clusters and is heated to X-ray radiating temperatures. X-ray spectroscopy is therefore the most important tool to obtain insights into the astrophysics of galaxy clusters. In this review I will recall crucial evolutionary problems in galaxy clusters and the achievements obtained by high-resolution X-ray spectroscopy. In 19 years since the launch of XMM-Newton, the Reflection Grating Spectrometer (RGS) has enabled transformational astrophysics and continues to provide extraordinary results owing to a unique, stable and excellent performance over two decades. Its exquisite combination of effective area and spectral resolution provided important discoveries such as the cooling flow problem, the constraints on turbulence and cooling-heating balance. The RGS is the only instrument to date that resolves the nitrogen, oxygen and neon lines in clusters, necessary to understand their chemical enrichment by supernovae and AGB stars. The X-ray emission lines in RGS spectra showed that the ICM plasma is overall in thermal equilibrium which was not obvious given the presence of energetic phenomena such as jets from supermassive black holes and mergers.

Soft X-ray plasma in the inner 200 pc and in the Galactic centre lobe

Gabriele Ponti[1,2], Florian Hofmann[2], Eugene Churazov[3,4], Mark R. Morris[5], Frank Haberl[2], Kirpal Nandra[2], Regis Terrier[6], Maica Clavel[7], Andrea Goldwurm[6,8]
[1] *Astronomico di Brera, Via E. Bianchi 46, I-23807 Merate (LC), Italy*
[2] *Max-Planck-Institut fuer Extraterrestrische Physik, Giessenbachstrasse 1, D-85748 Garching, Germany*
[3] *Max-Planck-Institut fuer Astrophysik, Karl-Schwarzschild-Str. 1, D-85748, Garching, Germany*
[4] *Space Research Institute (IKI), Profsoyuznaya 84/32, Moscow 117997, Russia*
[5] *Department of Physics and Astronomy, University of California, Los Angeles, CA 90095-1547, USA*
[6] *Unite mixte de recherche Astroparticule et Cosmologie, 10 rue Alice Domon et Leonie Duquet, F-75205 Paris, France*
[7] *Univ. Grenoble Alpes, CNRS, IPAG, F-38000 Grenoble, France*
[8] *Service dAstrophysique (DAp), IRFU/DRF/CEA-Saclay, F-91191 Gif-sur-Yvette Cedex, France*

I will review our knowledge of the soft X-ray emission at the Galactic centre (GC). Evidence has increasingly mounted in recent decades that outflows of matter and energy from the GC have shaped the observed structure of the MilkyWay on a variety of larger scales. On scales of ∼15pc, the GC has bipolar lobes, indicating broadly collimated outflows. On far larger scales, gamma-ray observations have identified the so-called Fermi Bubbles, implying that our GC has had a period of active energy release leading to the production of relativistic particles that now populate such huge cavities. At intermediate scales, radio astronomers have found the GC Lobe, an apparent bubble of emission seen only at positive Galactic latitudes, but again indicative of energy injection from near the GC. We will report the discovery of prominent X-ray structures on these intermediate scales above and below the plane, which appear to connect the GC region to the Fermi bubbles. We propose that these structures, which we term the GC Chimneys, constitute exhaust channels through which energy and mass, injected by a quasi-continuous train of episodic events at the GC, are transported from the central parsecs to the base of the Fermi bubbles.

The galaxy cluster mass scale: insights from X-rays

Gabriel Pratt[1]
[1] *CEA Saclay, Département d'Astrophysique*

The total mass of a galaxy cluster is one of its most fundamental properties. Together with the redshift, the mass links observation and theory, allowing us to use the cluster population to test models of structure formation and to constrain cosmological parameters. I summarise the state of the art in cluster mass estimation methods, and discuss how X-rays can give unique insights into the determination of cluster masses, and into the physical properties of the hot gas.

eROSITA on SRG

Peter Predehl[1]
[1] *MPE, Garching, Germany*

eROSITA (extended ROentgen Survey with an Imaging Telescope Array) is the main instrument on-board the Russian/German "Spectrum-Roentgen-Gamma" (SRG) mission. It will be launched on June 21/22 2019 from the Cosmodrome in Baikonur in Kazakhstan using the heaviest Russian launch vehicle Proton. eROSITA will perform the first imaging all-sky survey in the medium energy band. The main scientific goals are (a) to detect the hot intergalactic medium of 50-100 thousand galaxy clusters and groups and hot gas in filaments between clusters to map out the large scale structure in the Universe for the study of cosmic structure evolution, (b) to detect systematically all obscured accreting Black Holes in nearby galaxies and many (up to 3 Million) new, distant active galactic nuclei and (c) to study in detail the physics of galactic X-ray source populations, like pre-main sequence stars, supernova remnants and X-ray binaries.

Galaxy clusters observations: structure and dynamics of the ICM

Jeremy Sanders[1]
[1] *Max Planck Institute for Extraterrestrial Physics, Garching, Germany*

The majority of the baryonic matter in a galaxy cluster is in the form of a hot intracluster medium (ICM). Heated to temperatures of several tens of MK, it emits in the X-ray waveband, and is an excellent tracer of the physical processes taking place in galaxy clusters. I discuss recent work using detailed X-ray observations of nearby galaxy clusters to understand the process of feedback by active galactic nuclei (AGN) in their cores. These results reveal that in the Centaurus cluster the nucleus has been repeatedly active on timescales of tens of Myr. The metallicity of the ICM also acts as a tracer of the gas motions generated by AGN feedback. I also present initial results using a new technique to measure the dynamics of the intracluster medium using XMM-Newton X-ray data, revealing clues about the nature of cluster evolution and mergers.

Supernova Remnants in Nearby Galaxies

Manami Sasaki[1]
[1] *Remeis Observatory, University of Erlangen-Nürnberg, Germany*

Supernova remnants (SNRs) are the aftermath of stellar explosions, which inject large amounts of energy into the interstellar medium (ISM), carving out new structures and transferring kinetic energy to the ISM. They also act as recycling centers, which return elements processed in stars to the ISM, and cosmic particle accelerators. The evolution of SNRs can be best studied in soft X-ray line and continuum emission, since they mainly consist of very hot plasma (10^6 - 10^7 K). While it is difficult to observe these soft X-ray sources in our own Galaxy due to absorption by matter in the Galactic plane, the Magellanic Clouds as well as the nearby spiral galaxies M31 and M33 are ideal targets to study particular SNRs in detail and the SNR population in a galaxy as a whole. I will give an overview of the studies of SNRs in the Local Group galaxies carried out with XMM-Newton and discuss prospects for future studies.

Evolution of Pulsar Wind Nebulae Inside Supernova Remnants

Tea Temim[1]
[1] *Space Telescope Science Institute*

Composite supernova remnants (SNRs) are those consisting of both a central pulsar that produces a wind of synchrotron-emitting relativistic particle and a supernova (SN) blast wave that expands into the surrounding interstellar medium (ISM). The evolution of the pulsar wind nebula (PWN) is coupled to the evolution of its host SNR and characterized by distinct stages, from the PWNs early expansion into the unshocked SN ejecta to its late-phase interaction with the SNR reverse shock. I will present an overview of the various evolutionary stages of composite SNRs and show how the signatures of the PWN/SNR interaction observed at X-ray, optical, infrared, and radio wavelengths can reveal important information about the innermost SN ejecta, freshly formed dust, and the SN progenitor. I will also discuss recent X-ray observations and hydrodynamical modeling of evolved systems in which the PWN interacts with the SNR reverse shock and discuss their implications for our general understanding of the structure and evolution of composite SNRs.

Unravelling the physics of the intracluster medium with cold fronts

Stephen Walker[1]
[1]*NASA Goddard Space Flight Center*

Deep observations of nearby galaxy clusters with Chandra have revealed mysterious concave bay structures in the central regions of a number of systems (Perseus, Centaurus and Abell 1795), which have similar X-ray and radio properties. These bays have all the properties of cold fronts, where the temperature rises and density falls sharply, but are concave rather than convex. By comparing to simulations of gas sloshing, we find that the bay in the Perseus cluster bears a striking resemblance in its size, location and thermal structure, to a giant (50 kpc) roll resulting from Kelvin-Helmholtz instabilities. Moving away from cluster cores, I will present new deep Chandra observations of the outer regions of the Perseus cluster, providing the clearest view of a colossal large scale cold front lying at half the cluster virial radius. We have found exciting new structures in this cold front, providing powerful new insights into the physical properties of the ICM.

Recombining plasma in mixed-morphology supernova remnants: discovery and progress in the last decade

Hiroya Yamaguchi[1]
[1]*JAXA/ISAS*

Presence of recombining plasma in several supernova remnants (SNRs), first suggested by ASCA observations, was anchored by the discovery of strong radiative recombination continua in Suzaku spectra of IC443 and W49B. This discovery was surprising, because X-ray-emitting SNRs were thought to have ionizing plasma in general. Since then, similar spectral features have been detected from dozens of SNRs, implying that the recombining plasma state is not uncommon for a certain type of SNRs. These observations indicate that such SNRs are associated with the so-called mixed-morphology class, characterized by a centrally-peaked X-ray profile and rim-brightened radio emission. However, the physical processes to form the recombining plasma have been elusive for a long while. Recent observations of W49B with NuSTAR and W44 with XMM-Newton have dramatically changed the situation, indicating clear evidence that two distinct mechanisms can work in formation of the recombining plasma: adiabatic cooling and thermal conduction. I will review the observational and theoretical progress made in the last decade and discuss future prospect for high-resolution spectroscopy of the recombining plasma with XRISM and Athena.

Chapter 2

Supernova Remnants

A novel method for component separation of extended sources in X-ray astronomy

Adrien Picquenot[1], Fabio Acero[1], Jerome Bobin[1], Gabriel Pratt[1], Pierre Maggi[2], Jean Ballet[1]
[1] *CEA-Saclay, Laboratoire AIM*
[2] *Observatoire Astronomique de Strasbourg*

Spectro-imaging instruments such as X-ray detectors allow investigation of the spatial and spectral properties of extended sources. In these sources, the different physical components are projected along the line of sight and the perceived signal is entangled. Extracting the intrinsic spatial and spectral information of the individual components from this data is a challenging task. Current analysis methods do not fully exploit the 2D-1D (X,Y,E) nature of the data, as the spatial and spectral information are often considered separately. With the current deep archival observations and in preparation for the next generation of telescopes, we need to explore new ways to analyse X-ray data by drawing from the most advanced signal processing techniques. Here we investigate the application of a blind source separation algorithm that jointly exploits the spectral and spatial signatures of each component in order to disentangle them. We explore the capabilities, in an X-ray context, of the Generalized Morphological Component Analysis, initially developed to extract an image of the Cosmic Microwave Background from Planck data. We will present a benchmark of the method using a supernova remnant toy model and show preliminary results on the Chandra Cassiopeia A and prospects for Athena X-IFU.

Plasma flow properties in the pulsar wind nebula 3C 58 investigated with a *NuSTAR* hard X-ray observation

Hongjun An[1]
[1] *Chungbuk National University, Cheongju-si, South Korea*

We present hard X-ray properties of the TeV-detected pulsar wind nebula 3C 58 investigated with a new *NuSTAR* observation. We measure energy dependent morphologies and spatially resolved spectra of the PWN to infer properties of the plasma flow in it. We find that the PWN becomes smaller with increasing energy, possibly due to synchrotron burn-off effects. The spectrum becomes softer with distance from the central pulsar and saturates at $R{\sim}75''$ as found in previous *Chandra* and *XMM-Newton* studies. This suggests that particle diffusion plays important roles in the plasma flow in this PWN. In addition, we find a hint of a spectral cutoff at $\sim$25 keV which implies that particles can be accelerated to $\sim$140 TeV (for an assumed B of 80μ G) in the relativistic shock of the PWN. We construct a broadband spectral energy distribution (SED) of 3C 58 and model the SED using a synchrotron-Compton scenario with diffusion to infer plasma flow properties in the PWN.

Smoothed Particle Inference Analysis of Supernova remnant DEM L71

Vikram Dwarkadas[1], Kari Frank[2], Aldo Panfichi[1], Ryan Crum[3], David Burrows[3]
[1] *University of Chicago*
[2] *CIERA, Northwestern University*
[3] *Penn State University*

Supernova remnants (SNRs) are complex, three-dimensional objects; properly accounting for this complexity when modeling the resulting X-ray emission presents quite a challenge and makes it difficult to accurately characterize the properties of the full SNR volume. We apply for the first time a novel analysis method, Smoothed Particle Inference, that can be used to study and characterize the structure, dynamics, morphology, and abundances of the entire remnant with a single analysis. We apply the method to the Type Ia supernova remnant DEM L71. We present histograms and maps showing global properties of the remnant, including temperature, abundances of various elements, abundance ratios, and ionization age. Our analysis confirms the high abundance of Fe within the ejecta of the supernova, which has led to it being typed as a Ia. We demonstrate that the results obtained via this method are consistent with results derived from numerical simulations carried out by us, as well as with previous analyses in the literature. At the same time, we show that despite its regular appearance, the temperature and other parameter maps exhibit highly irregular substructure which is not captured with typical X-ray analysis methods.

Deep X-ray study of the supernova remnant LMC-N132 with XMM-Newton

S. Estrada-Dorado[1], J.A. Toala[1]
[1] *Instituto de Radioastronomia y Astrofisica (IRyA - UNAM, Mexico)*

We present the analysis of *XMM-Newton* observations of the supernova remnant N132D located in the Large Magellanic Cloud (LMC). LMC-N132D has been observed during the past 18 yrs with the EPIC (MOS1+MOS2+pn) and RGS (1+2) instruments. The total observation time on source is more than 1 Ms with each instrument which allowed us to perform a deep study of the X-ray properties of this remnant.

Discovery of a jet-like structure with overionized plasma in the SNR IC 443

Emanuele Greco[1,2], Marco Miceli[1,2], Salvatore Orlando[2], Giovanni Peres[1,2], Eleonora Troja[3,4], Fabrizio Bocchino[2]
[1] *Università degli studi di Palermo - Dipartimento di Fisica e Chimica*
[2] *INAF-Osservatorio Astronomico di palermo*
[3] *NASA Goddard Space Flight Center, 8800 Greenbelt RD, Greenbelt, MD 20771, USA*
[4] *Department of Astronomy, University of Maryland, College Park, MD 20742-4111, USA*

IC443 is a supernova remnant (SNR) located in a complex environment and interacting with nearby clouds. Indications for the presence of overionized plasma have been found though the possible physical causes of overionization are still debated. Moreover, because of its peculiar position and proper motion, it's not clear whether the pulsar wind nebula (PWN) within the remnant is the relic of the progenitor star or a rambling one seen in projection on IC443. We addressed the study of the IC443 X-ray emission in order to investigate the relationship PWN-remnant, the presence and origin of overionization. We identified an elongated (jet-like) structure with Mg-rich plasma in overionization. The head of the jet interacts with a molecular cloud and the jet is aligned with the position of the PWN at the instant of the explosion. The direction of the jet of ejecta is consistent with the direction of the PWN jet. Our discovery enlarge the sample of core-collapse SNRs with collimated ejecta structures. IC443's jet is the first one showing overionized plasma, possibly associated with the adiabatic expansion of ejecta. The match between the jet's direction and the original position of the PWN supports the association between the neutron star and IC443.

Spatially Resolved Spectroscopy of the Supernova Remnant N63A in the Large Magellanic Cloud

Hideaki Matsumura[1], Hidetoshi Sano[2,3], Yumiko Yamane[3], Kengo Tachihara[3], Manami Sasaki[4], Yasuo Fukui[2,3]
[1] *Kavli Institute for the Physics and Mathematics of the Universe (WPI), The University of Tokyo, Chiba, Japan*
[2] *Institute for Advanced Research, Nagoya University, Nagoya, Japan*
[3] *Department of Physics, Nagoya University, Nagoya, Japan*
[4] *Dr. Karl Remeis-Sternwarte, Friedrich-Alexander-Universita t Erlangen-Nu rnberg, Bamberg, Germany*

Plasma evolution in supernova remnants (SNRs) depends on their gaseous environment because the SNR plasma contains a lot of swept-up interstellar medium (ISM). The good angular resolution of recent radio observatories such as the ALMA allow us to resolve clumpy molecular clouds whose sizes below a few arcseconds. By comparison of the ALMA data and spatially resolved spectra of hot plasma with Chandra, it became possible to investigate the effect of the ISM on extragalactic SNRs. N63A is one of the brightest SNRs in the Large Magellanic Cloud, whose size is $81'' \times 67''$ (diameter of ~ 18 pc at a distance of 50 kpc). The remnant has optical lobes with near-infrared colors indicative of molecular shocks, suggesting that shocked molecular gas dominates the SNR. Using the ALMA data, we find clumpy molecular clouds embedded in the optical nebulae in the optical lobes. We analyze Chandra X-ray spectrum at position of the gas clumps and find that it can be well explained by an absorbed power-law model or a high-temperature plasma model, in addition to thermal plasma components. It implies that the shock-cloud interaction causes magnetic field amplification and shock ionization.

The XMM-Newton view of the supergiant shell SMC-SGS1

J.A. Toala[1], F. Quesada-Zuñiga[1], L.M. Oskinova[2], M.A. Guerrero[3]
[1]*Instituto de Radioastronomia y Astrofisica (IRyA - UNAM, Mexico)*
[2]*Institute for Physics and Astronomy (University of Potsdam, Germany)*
[3]*Instituto de Astrofisica de Andalucia (IAA-CSIC, Spain)*

The eastern wing of the Small Magellanic Cloud (SMC) provides us with an excellent laboratory to investigate the rôle of stellar feedback in the evolution of galaxies. We have used *XMM-Newton* to study the population of hot massive stars and their feedback in the supershell SMC-SGS 1. This allowed us to study the presence of diffuse hot gas, supernova remnants and X-ray binaries. The current observations cover an area of 90 per cent of the total and account for a total exposure time of more than 0.5 Ms. We present the preliminary results of the analysis of our data.

Diffuse X-ray emission from Wolf-Rayet bubbles unveiled with *XMM-Newton*

Jesus A. Toala[1], Martin A. Guerrero[2], You-Hua Chu[3]
[1]*Instituto de Radioastronomia y Astrofisica (IRyA - UNAM, Mexico)*
[2]*Instituto de Astrofisica de Andalucia (IAA-CSIC, Spain)*
[3]*Institute of Astronomy and Astrophysics (ASIAA, Taiwan)*

Massive stars are the main actors that drive the dynamics of the interstellar medium (ISM) in the Universe. When in groups, the combination of their powerful winds as well as the contribution from supernovae explosions create the so-called superbubbles. Understanding in detail the contribution from each star in the cluster is difficult and we must look at wind-blown bubbles created around single massive stars. In particular, single Wolf-Rayet (WR) stars are capable of creating large cavities in the ISM with radii of tens of parsec. *XMM-Newton* has been a key instrument in unveiling the properties of the hot gas created as the result of the winds from WR stars and the ISM. In this talk we review our recent view of the production of diffuse X-ray emission from WR nebulae achieved by *XMM-Newton*.

Three-dimensional MHD modeling of SNR IC 443: effects of the inhomogeneous medium in shaping the remnant morphology

Sabina Ustamujic[1], Salvatore Orlando[1], Emanuele Greco[2,1], Marco Miceli[2,1], Fabrizio Bocchino[1], Giovanni Peres[2,1]
[1]*INAF - Osservatorio Astronomico di Palermo*
[2]*Università degli Studi di Palermo - Dipartimento di Fisica e Chimica*

In this study we aim at investigating the effects of the inhomogeneous medium in shaping the remnant morphology of IC 443 after the supernova (SN) explosion. The distribution of the interstellar medium in the vicinity of the supernova remnant (SNR) plays a fundamental role for our understanding of the morphology and later evolution. In particular, IC443 is a SNR located in a quite complex environment: it interacts with a molecular cloud in the northwestern and southeastern areas and with an atomic cloud in the northeast. We have developed a 3D MHD model for SNR IC 443 describing the interaction of the SNR with the environment, parametrized in agreement with the results of the multiwavelength data analysis. In this poster we present our preliminary results.

G7.7−3.7: A Young Supernova Remnant Probably Associated with the Guest Star in 386 CE (SN 386)

Ping Zhou[1], Jacco Vink[1], Geng Li[2], Vladimir Domcek[1]
[1]*University of Amsterdam*
[2]*National Astronomical Observatories, Chinese Academy of Sciences*

Although the Galactic supernova rate is about two per century, only few supernova remnants (SNRs) are associated with historical records. There are a few ancient Chinese records of guest stars that are probably sightings of supernovae for which the associated SNRs are not established. We report an X-ray study of the SNR G7.7−3.7, as observed by XMM-Newton, and discuss its probable association with the guest star of 386 CE. This guest star occurred in the ancient Chinese asterism Nan-Dou, which is part of Sagittarius. The X-ray emission is characterized by an under-ionized plasma with subsolar abundances, a temperature of 0.4–0.8 keV, and a density of around 0.5 cm^{-3}. A small shock age of about 1.2 ± 0.6 kyr is inferred from the low ionization timescale of the X-ray arc. The low foreground absorption made the supernova explosion visible to the naked eyes on the Earth. The position of G7.7−3.7 is consistent with the event of 386 CE, and the X-ray properties suggest that also its age is consistent. Interestingly, the association between G7.7−3.7 and guest star 386 would suggest the supernova to be a low-luminosity supernova, in order to explain the not very long visibility (2–4 months) of the guest star.

Chapter 3

Galaxies

Missing baryons and the warm-hot circumgalactic medium of late type galaxies NGC5746 and NGC3221

Anjali Gupta[1,2], Smita Mathur[2], Sanskriti Das[2], Fabrizio Nicastro[3], Yair Krongold[4], Cody Null[1]
[1]*Columbus State Community College*
[2]*Ohio State University,*
[3]*Observatorio Astronomico di Roma - INAF*
[4]*Instituto de Astronomia, Universidad Nacional Autonoma de Mexico*

Late-type galaxies are missing a large fraction of their baryonic mass, some of which is expected to be in the hot gaseous halo. However, searches of such a circumgalactic medium (CGM) have given mixed results. Theoretical models suggest that the CGM properties depend on galaxy properties such as gravitational mass, stellar mass and specific star formation rate (sSFR). Observations so far have focused on galaxies with high mass and low sSFR. NGC5746 and NGC3221 have smaller stellar masses with lower and higher sSFRs, respectively, probing an unexplored range of parameter space. I will present our Suzaku/Chandra/XMM-Newton observations probing the CGM of these galaxies in emission. I will discuss our results on the detection and characterization of the warm-hot CGM in NGC5746 and NGC3221.

Unravelling the origin of extended X-ray emission surrounding FR II radio galaxies

Ana Jimenez-Gallardo[1,2], Francesco Massaro[1,2,3,4], Raffaele D'Abrusco[5], Almudena Prieto[6,7], Alessandro Paggi[1,2,3], Federica Ricci[8], Chiara Stuardi[1,2,9,10], Belinda Wilkes[5], Christopher O'Dea[11,12], Stefi Baum[11,13], Elisabetta Liuzzo[10], Harold Peña-Herazo[1,3,14]
[1]*Dipartimento di Fisica, Università degli Studi di Torino, via Pietro Giuria 1, 10125 Torino, Italy*
[2]*INAF-Osservatorio Astrofisico di Torino, via Osservatorio 20, 10025 Pino Torinese, Italy*
[3]*Istituto Nazionale di Fisica Nucleare, Sezione di Torino, I-10125 Torino, Italy*
[4]*Consorzio Interuniversitario per la Fisica Spaziale (CIFS), via Pietro Giuria 1, I-10125, Torino, Italy*
[5]*Smithsonian Astrophysical Center, 60 Garden Street, Cambridge, MA 02138, USA*
[6]*Departamento de Astrofísica, Universidad de La Laguna, E-38206 La Laguna, Tenerife, Spain*
[7]*Instituto de Astrofísica de Canarias (IAC), E-38200 La Laguna, Tenerife, Spain*
[8]*Instituto de Astrofísica and Centro de Astroingeniería, Facultad de Física, Pontificia Universidad Católica de Chile, Casilla 306, Santiago 22, Chile*
[9]*Dipartimento di Fisica e Astronomia, Università di Bologna, via Piero Gobetti 93/2, I-40129 Bologna, Italy*
[10]*Istituto di Radioastronomia, INAF, via Gobetti 101, I-40129, Bologna, Italy*
[11]*University of Manitoba, Dept. of Physics and Astronomy, Winnipeg, MB R3T 2N2, Canada*
[12]*School of Physics & Astronomy, Rochester Institute of Technology, 84 Lomb Memorial Dr., Rochester, NY 14623, USA*
[13]*Center for Imaging Science, Rochester Institute of Technology, 84 Lomb Memorial Dr., Rochester, NY 14623, USA*
[14]*Instituto Nacional de Astrofísica, Óptica y Electrónica, Puebla, Mexico*

We carried out an extensive X-ray analysis of surface brightness profiles of a sample of FRII radio galaxies. We aimed at assessing the extension of the X-ray diffuse emission along the radio structure as well as in the cross-cone direction perpendicular to the radio axis. We also addressed the hotspot detection significance over the local X-ray background. To obtain a complete characterization of the selected FRII radio galaxies, we compared X-ray images with radio maps at 100 MHz and investigated the possible presence of a surrounding galaxy cluster/group by inspecting optical and infrared observations. The sample of FRII radio galaxies was selected from the radio sources of the Third Cambridge catalog observed during the Chandra snapshot survey. These observations span a range of exposure times between 8 and 20 ks and were obtained during Chandra Cycles A09, A012, A013, A015, A017 and A019. As a preliminary result, we find that around 40% of the sources clearly show extended X-ray emission up to hundreds of kpc both along the radio axis and in cross-cone direction. Additionally, the presence of diffuse X-ray emission with no counterparts at radio frequencies around 1 GHz shows tentative evidence of CMB quenching.

X-ray Early Type Galaxy Atlas

Dong-Woo Kim[1], CGA Team[1]
[1] *Center for Astrophysics Harvard & Smithsonian*

The hot ISM in early type galaxies (ETGs) plays a crucial role in understanding their formation and evolution. The structural features of the hot gas identified by Chandra and XMM-Newton observations point to key evolutionary mechanisms, (e.g., AGN and stellar feedback, merging history). In our X-ray Galaxy Atlas project, we systematically analyzed the archival Chandra (XMM-Newton) data of 70 (50) ETGs and produced uniform data products for the hot gas properties. The primary data products are spatially resolved 2D spectral maps of the hot gas from individual galaxies. We emphasize that new features can be identified in the spectral maps which are not readily visible in the surface brightness maps or 1-dimensional radial profiles. Utilizing our data products, we will discuss a few focused science topics, including the hot ga morphology in relation to feedback and environmental effects; the hot gas global properties and scaling relations; and the possibility of the universal T profile in ETGs.

Multi-Wavelength Analysis of the X-ray Spur in the Large Magellanic Cloud

Jonathan Knies[1], Manami Sasaki[1], Yasuo Fukui[2], Kisetsu Tsuge[2], Frank Haberl[3], Miroslav Filipovic[4], Sean Points[5], Patrick Kavanagh[6]
[1] *Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany*
[2] *Nagoya University, Nagoya, Japan*
[3] *Max-Planck-Institut für extraterrestrische Physik, Garching, Germany*
[4] *Western Sydney University, Sydney, Australia*
[5] *Cerro Tololo Inter-American Observatory, La Serena, Chile*
[6] *Dublin Institute for Advanced Studies, Dublin, Ireland*

Large HI gas structures have been found in the Large Magellanic Cloud, which appear to have collided and triggered the formation of the massive star cluster R136 and the giant HII region 30 Doradus. South of 30 Doradus, a large ($\sim 1\,\mathrm{kpc}$) X-ray emitting structure called the X-ray spur was observed, which appears to be anti-correlated with the colliding HI gas components.

Using XMM-Newton, we have studied the X-ray spur to determine the properties of the hot, X-ray emitting plasma. Our X-ray analysis and multi-wavelength comparison has allowed us to investigate the origin of the X-ray spur and related interactions in the interstellar medium. We performed a spectral analysis using both new and archival XMM-Newton observations of the entire structure and cross-correlated the X-ray emission with the HI data, as well as with optical Hα and [S II] images.

We obtained higher plasma temperatures at the position of the X-ray spur compared to the surrounding interstellar plasma. In contrast, almost no Hα emission or massive stars were observed in the X-ray spur. These results suggest that the plasma may have been heated by shocks of the colliding HI gas rather than by the combined effect of massive stellar winds/supernova remnants.

Supernovae-driven Galactic Outflows and the X-ray Emission and Absorption of Galaxy Coronae

Miao Li[1], Stephanie Tonnesen[1]
[1] *Center for Computational Astrophysics, Flatiron Institute, New York, USA*

The missing baryon and missing metals problems are the two major challenges for galaxy formation. The missing matter most likely resides in the warm-hot (10^{5-7} K) medium beyond galaxies. Hot outflows driven by supernovae carry the majority of energy and metals, providing a natural solution to these problems. X-ray emission from hot corona around spiral galaxies, observed by XMM-Newton and Chandra, provides critical information about the outflows and its interaction with the pre-existing gas. We use 3D galactic scale simulations to investigate this interaction, using physical outflow models calibrated by small-box, high-resolution simulations. We construct mock X-ray emission maps and absorption maps of galaxy coronae. I will talk about how the X-ray luminosity and its spatial distribution are related to the star formation activities in the galaxies, and in particular, how the simulated maps compared to the current observations. With a robust feedback model and current observational constraints, we predict emission and linewidths of hot gas further away from galaxies. This can be detected by future missions like ATHENA with unprecedented sensitivities and spectral resolutions.

A Comparative study of the X-ray photon indices of broad and narrow-line Seyfert 1 galaxies.

Vineet Ojha[1], Hum Chand[2], Gulab Chand Dewangan[3], Suvenu Rakshit[4]
[1] *Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India*
[2] *Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India*
[3] *Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, India*
[4] *Finnish Centre for Astronomy with ESO (FINCA), University of Turku, Quantum, Vesilinnantie 5, 20014 University of Turku,*

We have studied the soft X-ray (0.1-2 keV) properties for a sample of 200 Narrow-line Seyfert 1 (NLSy1) and 132 Broad-line Seyfert 1 (BLSy1) galaxies observed by ROSAT and/or XMM-Newton. A systematic homogeneous analysis is carried out to estimate their soft X-ray photon index (Γ_X) and its correlations with other parameters of nuclear activities such as Eddington ratio (R_{Edd}), bolometric luminosity (L_{bol}), black hole mass (M_{BH}) and the width of the broad component of Hβ line (FWHM(Hβ)). In our analysis, we found (i) the existence of bimodality of the Γ_X, R_{Edd} distributions among NLSy1 and BLSy1 galaxies, and (ii) the significant positive $\Gamma_X - R_{Edd}$ correlations for both the samples of NLSy1 and BLSy1 galaxies. To lift the degeneracy due to possible soft X-ray excess, we have also extended our analysis for the quantitative comparison in hard X-ray (2-10 keV) by analysing a sample of XMM-Newton detected 56 NLSy1 and 51 BLSy1 galaxies. The observed significant $\Gamma_X - R_{Edd}$ correlations for our sample of NLSy1 and BLSy1 galaxies appear to be qualitatively similar to the luminous AGNs derived based on their hard X-ray photon index, which is generally consistent with the theoretical prediction of X-ray production by a disc-corona system.

The Chandra 3C Snapshot Survey: The Story So Far

Alessandro Paggi[1,2], Francesco Massaro[1,2,3,4], Stefi Baum[5,6], Raffaele D'Abrusco[7], William Forman[7], Ana Jimenez[1,3,8,9], Ralph Kraft[7], Joanna Kuraszkiewicz[7], Elisabetta Liuzzo[10], Valentina Missaglia[7], Christopher O'Dea[5,11], Federica Ricci[12], Chiara Stuardi[13,14], Grant Tremblay[7], Belinda Wilkes[7]
[1]*INAF-Osservatorio Astrofisico di Torino, Pino Torinese, Italy*
[2]*INFN, Sezione di Torino, Torino, Italy*
[3]*Dipartimento di Fisica, Università degli Studi di Torino, Torino, Italy*
[4]*Consorzio Interuniversitario per la Fisica Spaziale (CIFS), Torino, Italy*
[5]*University of Manitoba, Dept. of Physics and Astronomy, Winnipeg, Canada*
[6]*Carlson Center for Imaging Science, Rochester, USA*
[7]*Center for Astrophysics — Harvard & Smithsonian (CfA), Cambridge, USA*
[8]*Departamento de Astrofísica, Universidad de La Laguna,Tenerife, Spain*
[9]*Instituto de Astrofísica de Canarias (IAC),Tenerife, Spain*
[10]*INAF-Istituto di Radioastronomia, Bologna, Italy*
[11]*School of Physics & Astronomy, Rochester Institute of Technology, Rochester, USA*
[12]*Instituto de Astrofísica and Centro de Astroingeniería, Pontificia Universidad Católica de Chile, Santiago, Chile*
[13]*Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy*
[14]*INAF-Istituto di Radioastronomia, Bologna, Italy*

We present the results of the Chandra 3C Snapshot Survey aimed at extending the wavelength coverage of the 3CR catalog with observations of Chandra X-ray observatory. The main aims of this survey are 1) studying the X-ray emission, as a function of z and radio power, arising from jet knots, hotspots and nuclei of radio sources, 2) investigating the nature of their large scale environment and 3) searching for observational evidence of AGN interactions with the hot gas in galaxies, groups and clusters of galaxies. This survey has so far collected data from more the 100 radio galaxies with $z < 1.5$ that allowed the construction of flux maps and photometric results in different energy bands for the nuclei and other radio structures (i.e., jet knots, hot spots, lobes), hardness ratio estimates, and spectral analysis of the stronger sources. A sizable fraction ($\sim 60\%$) of the nuclei studied in this survey show evidence for significant intrinsic absorption ($N_H > 5 \times 10^{22}$ cm^{-2}). In addition we found X-ray emission co-spatial with hot-spots and jets, extended X-ray emission in 15 sources and clusters cavities, providing important informations for the study of the surrounding environments of these radio sources.

Metal abundances in the MACER simulations of the hot interstellar medium

Silvia Pellegrini[1], Zhaoming Gan[2], Ena Choi[3], Jeremiah Ostriker[3], Luca Ciotti[1]
[1]*Dept. of Physics and Astronomy, University of Bologna, Italy*
[2]*Shanghai Astronomical Observatory, CAS, Shanghai, China*
[3]*Dept. of Astronomy, Columbia University, New York, USA*

A hot plasma is the dominant phase of the ISM of early-type galaxies. Its origin can reside in stellar mass losses, residual gas from the formation epoch, and accretion from outside. Its evolution is linked to the dynamical structure of the host galaxy, to the supernova and AGN feedback input, and to (late-epoch) star formation. One important clue about the origin and evolution of the hot gas comes from the abundances of heavy metals, that have been studied with increasing detail with XMM-Newton and Chandra. I will present recent hydrodynamical simulations of the hot gas evolution with the MACER code that include the above processes, and where several chemical species, originating in AGB stars and supernovae of type Ia and II, have also been considered. The high resolution, of few parsecs in the central region, allowed to track the metal enrichment, transportation and dilution throughout the galaxy. The comparison with observed abundances reveals agreement (as for the AGN-wind region), but also discrepancies (as for the diffuse hot gas), that point to a revision of standard assumptions, and/or to the importance of neglected effects (as those due to the dust), and/or to uncertainties in deriving abundances from the X-ray spectra.

X-ray Spectra of Hot Circumgalactic Medium around Spiral galaxies: Connecting Simulations to Observations

Aditi Vijayan[1,2], Miao Li[3]
[1] *Raman Research Institute, Bangalore, India*
[2] *Indian Institute of Science, Bangalore, India*
[3] *CCA, Flatiron Institute, New York, US*

Star formation in galaxies drives outflows of hot gas into the circumgalactic medium (CGM). The hot component of such outflows is detected as diffuse extra-planar X-ray emission using instruments such as Chandra and XMMNewton. The X-ray spectra help constrain the temperature of this plasma, which gives important information for the feedback model. When interpreting the current spectra, simplified assumptions are made, such as 1-T or 2-T model, with a uniform metallicity. The actual condition of the extra-planar gas is much more complicated, because of interaction between outflows and halo gas. We have conducted 3-D hydrodynamic simulations of disk galaxies, using an accurate feedback model adopted from high-resolution, small-box simulations. We analyze the physical properties of galaxy corona, which show a broad distribution of density, temperature and metallicity. We use Pyxsim and SOXS to construct synthetic spectra from simulation data, and compare with current low resolution observations from Chandra. Furthermore, we make mock spectra for the future mission ATHENA. With its unprecedented spectral resolution, emission line studies can be conducted for Milky Way-size galaxies for the first time. We will discuss how this will constrain the temperature, composition and velocity of galaxy coronae, which provide critical diagnostics for feedback physics

Can we observe reconnection heating in spiral galaxies?

Marek Wezgowiec[1], Matthias Ehle[2], Rainer Beck[3], Marian Soida[1], Marek Urbanik[1]
[1] *Obserwatorium Astronomiczne Uniwersytetu Jagiellonskiego, Kraków, Poland*
[2] *ESA-ESAC, Villanueva de la Cañada, Spain*
[3] *MPIfR, Bonn, Germany*

In some spiral galaxies the so-called ”magnetic arms” have been reported, being interarm areas with significant polarized radio emission that suggests high ordering of the magnetic field.The most prominent example of such a galaxy is NGC 6946.
The nature of these magnetic features is still under debate. One of the possible explanations is the action of reconnection heating that could convert the energy of the magnetic field into thermal energy of the surrounding gas.
We summarize the analysis of the radio and X-ray emission (measured with XMM-Newton) from NGC 6946 and conclude that we might see hints for such reconnection heating (cf. Wezgowiec et al. A&A 585, 3, 2016).
A similar analysis is on-going for further galaxies: For one of them, M 83, we intend to present preliminary results.

XMM-Newton RGS spectroscopy of the M31 bulge: A past AGN half a million years ago

Shuinai Zhang[1], Li Ji[1]
[1] *Purple Mountain Observatory, Chinese Academic of Sciences, Nanjing, China*

Existing analysis already shows that the G-ratio of the OVII He triplet in the inner bulge of M31 is too high to be consistent with a simple optically-thin thermal plasma in collisional ionization equilibrium (CIE). Different processes that may affect the properties of diffuse hot plasma were proposed, such as resonance scattering (RS) and charge exchange (CX) with cool gas. To determine which physical process(es) may be responsible, we present a systematic spectroscopic analysis based on 0.8 Ms XMM-Newton/RGS data, together with complementary Chandra/ACIS-S images. The combination of these data enables us to reveal multiple non-CIE spectroscopic diagnostics, but we find neither CX nor RS explains all of them self-consistently. Alternatively, we find an AGN relic scenario provides a plausible explanation for essentially all the signatures. We have developed a spectral model of this relic, and estimate that an AGN was present at the center of M31 about half a million years ago with an ionizing luminosity of about 1E44 erg/s.

Hot gas over the arms of M51 traced by emission lines

Shuinai Zhang[1], Li Ji[1]
[1] *Purple Mountain Observatory, Chinese Academic of Sciences, Nanjing, China*

Galactic fountains operate in outer galaxy disks, where supernovae heat ambient gas to X-ray emission temperatures. However, the diffuse X-ray morphology in the spiral arms is often associated with recent active star formation, instead of supernovae that should be distributed in a larger region. To better trace the geometry and understand the properties of hot gas in nearby face-on galaxy M51, we extract intensity maps of OVIII and OVII lines based on XMM-Newton/RGS data. The line emission maps are discrepant from each other and from the broad-band X-ray morphology. Especially in the northern hot spot, the strong emission from OVIII and OVII forbidden lines and the lack of OVII resonance line suggest the charge exchange (CX) process due to the interaction of hot gas and cold ISM, which is consistent with the spectral modeling of the entire RGS spectrum. Nevertheless, CX is not obvious in the companion galaxy NGC 5195.

Chapter 4

Clusters of Galaxies

Probing galaxy cluster magnetic fields with line-of-sight rotation measures

Hans Boehringer[1], Gayoung Chon[1], Philipp Kronberg[2]
[1] *Ludwig-Maximilians-Universitaet, Muenchen*
[2] *University of Toronto*

To search for a signature and strength of an intracluster magnetic field, we compare measurements of Faraday rotation of polarised extragalactic radio sources in the line-of-sight of galaxy clusters with those outside. We correlate a catalogue of 1383 rotation measures of polarised radio sources with X-ray galaxy clusters from our CLASSIX survey. We find a significant excess of the dispersion of the rotation measures in the cluster regions. Since the observed rotation measure is the result of Faraday rotation in several, presumably uncorrelated magnetised cells of the intracluster medium, the interesting quantity is the dispersion of the rotation measure for an ensemble of clusters. We find a standard deviation of the rotation measure inside our fiducial cluster radius of about 120 +- 21 rad m-2, compares to about 56 +- 8 rad m-2 outside. The observed dispersion of the rotation measure increases with the intracluster medium column density in the line-of-sight, and we deduce a magnetic field value of about 2 - 6 (l/10 kpc)-1/2 muG assuming a constant magnetic field strength, where l is the size of the coherently magnetised cells. This magnetic field energy density amounts to few percent of the average thermal energy density in clusters.

Multi-wavelength analyses of pre-merging galaxy clusters

Turgay Caglar[1]
[1] *Leiden Observatory*

Clusters of galaxies are the largest observed laboratories, which are formed around massive galaxies due to gravitational infall of other objects. Multi-wavelength investigations of galaxy clusters allow us to understand structure formation of the universe. One of the most interesting results of these investigations is the collisions between massive objects, such as cluster-cluster interactions, which are known as mergers. Throughout merger investigations, many intriguing physical outcomes have been identified such as the shock-heated plasmas, diffuse radio emissions, ram-pressure stripping etc. In this study, we aim to understand the dynamical structures of pre-merging galaxy clusters and physical processes throughout pre-mergers. We perform multi-wavelength analyses for a sample of galaxy clusters using archival X-Ray and optical data. Boundary conditions are studied by using relativistic equations. I will present the results from four merging galaxy clusters and discuss possible physical mechanisms throughout merger.

The role of helium in the ICM emission: implications and constraints

Stefano Ettori[1]
[1] *INAF-OAS Bologna, Italy*

I discuss the role of the helium abundance in the spectral analysis of the intracluster medium and how we can try to constrain it by a combination of X-ray and SZ measurements. I apply this method to our recent analysis of the X-COP sample, a now completed XMM LP that followed-up 12 nearby massive galaxy clusters selected to have a high signal-to-noise ratio in Planck maps.

Probes of rain and turbulence in hot halos

Massimo Gaspari[1]
[1] *Princeton University, Princeton, USA*

I will discuss recent main results aimed to test the properties of multiphase gas condensation/rain in the hot X-ray halos of galaxy groups and clusters. I will show the key multiwavelength correlations (X-ray - optical - radio) that arise between the 3 major phases (hot - warm - cold gas), in terms of kinematics (spectra) and thermodynamics (images). The ensemble and pencil-beam detections of spectral line broadening/shift are majorly complementary to reach a full view of the macro- and micro-scale multiphase precipitation, respectively. Power spectra of density/pressure fluctuations provide further key constraints on the hot halo kinematics and transport properties. Via detailed synthetic X-ray IFU observations, I will finally show how the next-generation X-ray missions as Athena will help us to accurately measure the turbulence and bulk motions in hot plasma halos up to the cluster outskirts.

A Study of the Merger History of the Galaxy Group HCG 62 Based on X-Ray Observations and Smoothed Particle Hydrodynamic Simulations

Dan Hu[1]
[1] *Shanghai Jiao Tong University, Shanghai, China*

We chose the bright compact group HCG 62, which has been found to exhibit both excess X-ray emission and high Fe abundance to the southwest of its core, as an example to study the impact of mergers on chemical enrichment in the intragroup medium. We first reanalyze the high-quality Chandra and XMM-Newton archive data to search for evidence of additional SN II yields, which is expected to be a direct result of the possible merger-induced starburst. We reveal that, similar to the Fe abundance, the Mg abundance also shows a high value in both the innermost region and the southwest substructure, forming a high-abundance plateau. Meanwhile, all the SN Ia and SN II yields show rather flat distributions in ¿0.1r 200 in favor of an early enrichment. Then, we carry out a series of idealized numerical simulations to model the collision of two initially isolated galaxy groups by using the GADGET-3 code. We find that the observed X-ray emission and metal distributions, as well as the relative positions of the two bright central galaxies with reference to the X-ray peak, can be well reproduced in a major merger with a mass ratio of 3 when the merger-induced starburst is assumed.

Enhanced Ram Pressure Stripping of Galaxies in Major Mergers and the formation of Jellyfish Galaxies

Matthew Hunt[1], Elke Roediger[1]
[1] *E.A. Milne Centre for Astrophysics, University of Hull, Hull, United Kingdom*

Galaxies experience ram pressure when they move through the intracluster medium (ICM); this can cause gas to be stripped out from a galaxy if the pressure exerted is great enough.

We address the effects of cluster mergers on the ram pressures experienced by galaxies within the clusters. Mergers create shockwaves in the ICM resulting in bulk motions and enhanced densities in the ICM, which is thought to rapidly enhance the ram pressure applied to galaxies. This enhanced ram pressure results in greater stripping forces on the galaxies, which can trigger gas stripped tails and star formation. This process of ram pressure stripping has been invoked to explain the formation of jellyfish galaxies with their star forming tails, shown through observations to be prominent in merging clusters.

Through hydrodynamical + N-body simulations we create a variety of idealised Major Mergers and locate where and when during the mergers galaxies would experience rapid increases in ram pressure, similar to that thought to create Jellyfish galaxies. We link these epochs and locations of enhanced ram pressure to further observables of cluster mergers such as the merger stage and the location of the merger shocks, and determine the impact of the projected direction.

100 deg^2 image of the Virgo Cluster

Melih Kara[1], Antonio Perez[1], Miriam Ramos-Ceja[1], Thomas Holger Reiprich[1]
[1]*Argelander Institute für Astronomie*

eROSITA X-ray telescope, a successor of XMM-Newton and other X-ray telescopes, is expected to launch in June 2019. eROSITA having a field of view (FoV) of $\sim$0.83 deg^2 will cover large scales. The Virgo cluster, being the closest cluster of galaxies and being the nucleus of Local Supercluster of galaxies within which our own Milky Way galaxy is situated is of particular interest.
This project aims to obtain a mosaic of all XMM-Newton images within 100 deg^2 of the Virgo cluster. Images in different spectral energy bands will be extracted. In addition, images cleaned from the point sources will also be presented to constrain the fainter emission from the outskirts. Once the data from eROSITA over the full Virgo cluster area have been collected, detailed comparisons in the overlapping areas will be performed.

A multiwavelength study of WHIM in Planck-detected superclusters: searching for the missing baryons

Alexander Kolodzig[1], Nabila Aghanim[1], Edouard Lecoq[1], Mathieu Langer[1], Victor Bonjean[1], Marian Douspis[1], Etienne Pointecouteau[2]
[1]*IAS, CNRS/Universite Paris-Sud, Universite Paris-Saclay, Orsay Cedex, France*
[2]*IRAP, Université de Toulouse, CNRS, CNES, UPS, Toulouse, France*

The warm-hot intergalactic medium (WHIM) is the best candidate to solve the *missing baryon problem* but its diffuse nature makes it challenging and expensive to observe. Recent stacking analyses have shown that WHIM within superclusters can account for a large fraction of the missing baryons, making superclusters one of the most suitable structures to study WHIM directly. However, stacking analyses are blind to many physical properties of interest. To overcome this difficulty, we are developing a comprehensive strategy based on a joint analysis of SZ, X-rays and galaxy-distribution of superclusters. Our aim is to accurately model the contribution of all known astrophysical components, where the instrumental background is properly taken into account. In this first study, we will show the results obtained for two Planck-detected triplet-cluster-systems with $\sim$130ks and $\sim$80ks XMM-Newton data. We will give an outlook for future X-ray missions, such as eROSITA and Athena.

Diffusive shock acceleration of Fe XXVI ions in galaxy clusters

Julia Kropotina[1], Andrei Bykov[1]
[1]*Ioffe Institute*

Hybrid kinetic simulations of multispecies collisionless shocks in hot plasma are presented. The realistic proton-helium plasma composition with small admixture of Fe XXVI ions is considered. The presence of diffusive shock acceleration is proved for all ions for the case of sound Mach number M=3 or greater. At the same time for lower Mach number the acceleration rate is much lower, in good agreement with full particle-in-cell simulations of Ha et al (2018). The higher acceleration efficiency for ions with greater mass-to-charge ratio is shown. The impact of various helium abundances on iron ions acceleration is discussed, as well as possibility of observational applications.

Physical properties of the X-ray gas as a dynamical diagnosis for galaxy clusters

Tatiana Lagana[1], Florence Durret[2], Paulo Lopes[3]
[1]*NAT, Universidade Cruzeiro do Sul, Sao Paulo, Brazil*
[2]*IAP, Institut d'Astrophysique de Paris, Sorbonne Universite, France*
[3]*Observatoirio do Valongo, Rio de Janeiro, Brazil*

Based on XMM-Newton EPIC data, we have computed the spatial distribution of the X-ray gas temperature (kT), pressure (P), entropy (S) and metallicity (Z) for 53 galaxy clusters. Our analysis shows that when clusters are spherically symmetric the cool-cores (CC) are preserved, the systems are relaxed with little signs of perturbation, and most of the CC criteria agree. The disturbed clusters are elongated, show clear signs of interaction in the 2D maps, and most do not have a CC. However, 16 well studied clusters classified as CC by at least four criteria show spectral maps that appear disturbed. All of these clusters but one show clear signs of recent mergers, with a complex structure and geometry but with a CC that remains preserved. Thus, although very useful for CC characterization, most diagnoses are too simplistic to reproduce the overall structure and dynamics of galaxy clusters. The complex structure of galaxy clusters can be reliably assessed through the 2D maps presented here, and coupled with a dynamical analysis based on galaxy redshifts that is presently under way.

Constraining Gas Clumping in Galaxy Clusters with X-ray Angular Power Spectra

Erwin Lau[1], Nico Cappelluti[1], Daisuke Nagai[2], Masato Shirasaki[3]
[1] *University of Miami, Coral Gables, FL, USA*
[2] *Yale University, New Haven, CT, USA*
[3] *National Astronomical Observatory of Japan, Mitaka, Japan*

Gas clumping in the outskirts of galaxy clusters is one of the major unexplored astrophysics in cluster formation. Due to the low surface brightness of the gas in cluster outskirts, it is extremely challenging to constrain gas clumping for individual clusters. On the other hand, the X-ray angular power spectrum of clusters allows us to statistically constrain the level of gas clumping, especially for low mass, high redshift clusters and groups. Using a physically motivated model of gas clumping, we provide the first constraint of gas clumping with the X-ray angular power spectrum measured from the ROSAT All-Sky Survey. We also provide forecasts of gas clumping with upcoming X-ray surveys, such as eROSITA and Athena.

Measuring cooling rates in cool-core galaxy clusters

Haonan Liu[1], Ciro Pinto[1,2], Andrew Fabian[1], Helen Russell[1], Jeremy Sanders[3]
[1] *University of Cambridge, Cambridge, United Kingdom*
[2] *ESTEC/ESA, Noordwijk, The Netherlands*
[3] *Max-Planck-Institut für extraterrestrische Physik, Garching, Germany*

Cool-core galaxy clusters are common at low redshifts, where the temperatures of the cooling X-ray emitting gas can drop below 1 keV, typically less than one-third of the bulk ICM temperature. The central radiative cooling time is much less than the age of clusters, suggesting that any strong cooling flow is suppressed by AGN feedback. Here we measure the rate of cooling in a sample of nearby cool-core clusters using the XMM RGS. The rates are less than 20 per cent of the cooling rates estimated in the absence of heating for 19 out of 22 clusters. Examining the cooling rate above and below an intermediate temperature of 0.7 keV, we find that the cooling rate at higher temperatures generally exceeds any residual cooling below 0.7 keV. Our findings suggest that AGN feedback is highly efficient at balancing cooling and is most effective at lower temperatures. We also compare the cooling rates above 0.7 keV to the energy required to support the optical/UV/IR emission in the optical-UV emitting filaments, and find that they are sufficient only in low-luminosity objects. The filaments in higher luminosity objects, if powered by the surrounding gas, must rely on hotter gas.

Nitrogen abundance in the X-ray halos of clusters and groups of galaxies

Junjie Mao[1,2], Jelle de Plaa[2]
[1]*Department of Physics, University of Strathclyde, Glasgow G4 0NG, UK*
[2]*SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands*

The line-rich X-ray spectra of groups and clusters of galaxies indicated that these large scale structures are enriched with metals. The observed elemental abundances are footprints of time-integrated yields of various stellar populations. We examined the high-resolution X-ray spectra of the chemical evolution RGS sample (CHEERS), which contains 44 nearby groups and clusters of galaxies. We can well constrain the nitrogen abundance in the core ($r/r_{500} < 0.05$) of one cluster of galaxies and seven groups of galaxies. Low- and intermediate-massive stars in the asymptotic giant branch are the main metal factories of nitrogen. The abundance of odd-Z elements like nitrogen is more sensitive to the initial metallicity of the stellar progenitors, thus providing more constraints on the chemical enrichment model. Nevertheless, accurate abundance measurements of odd-Z elements (e.g. N, Al, and Mn) are challenging for the current generation of spectrometers. Future missions like XRISM and XIFU will certainly advance our knowledge on the enrichment of odd-Z elements.

Thermodynamical properties of three X-ray low surface brightness clusters

Naomi Ota[1]
[1]*Nara Women's University/University of Bonn*

We present results of Suzaku and XMM-Newton observations of three nearby galaxy clusters, A76, A1631, and A2399 (Ota et al. 2013; Babazaki et al. 2018; Mitsuishi et al. 2018). They are classified as low X-ray surface brightness (LSB) clusters and have highly diffuse X-ray emission. So far, only several LSB clusters have been identified in the REXCESS sample, which make up 5-10 percent of the RASS cluster sample. To study their dynamical state, we derived radial profiles of gas temperature, density, and entropy out to large radii with Suzaku. Common to all three objects, the gas density is extremely low for the observed high temperature. The radial entropy profile is flat and the central entropy is exceptionally high ($\sim 300 - 400\mathrm{keVcm}^2$), which is not readily explained by either gravitational heating or preheating. The X-ray morphology is clumped and irregular, and the spatial distributions of gas and galaxies appear to be different. In addition, we discovered a cold front in A2399. Based on the results, we suggest that a post-merger scenario may explain the observed properties of the LSB clusters. We will briefly discuss prospects for future study of this class of clusters.

Metal enrichment in galaxy group IC 1262

Satish S. Sonkamble[1], Dharam V. Lal[1]
[1]*National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, Pune - 411 007, India*

Metal enrichment of a unique rich galaxy group IC 1262, showing cold fronts along east–west which is (nearly) orthogonal to the north–south radio jet is presented. We use archival *Chandra* and GMRT data to study the metal transport due to sloshing cold front and radio jets. The profile of the metallicity along the norther radio jet shows a steady decline in metallicity until ∼93 kpc, following which it begins to increase and peaks at ∼140 kpc. Whereas it rises until ∼46 kpc and then it steadily declines. Two strong surface brightness discontinuities, which are due to sloshing cold fronts are detected in the intracluster medium. There is a hint of a discontinuity in the metallicity profile along the detected cold fronts, in particular towards east. Finally, the gas in the inner regions of the cold front is ∼45 per cent more enriched than the gas outside the cold front, suggesting that the mixing process is not efficient.

Iron abundance distribution in the hot gas of merging galaxy clusters

Igone Urdampilleta[1,2], Francois Mernier[1,3,4], Jelle S. Kaastra[1,2], Aurora Simionescu[1,2], Jelle de Plaa[1], Sinancan Kara[5], Nihal Ercan[5]
[1]*SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands*
[2]*Leiden Observatory, Leiden University, PO Box 9513, 2300 RA Leiden, The Netherlands*
[3]*MTA-Eötvös University Lendület Hot Universe Research Group, Pázmány Péter sétány 1/A, Budapest, 1117, Hungary*
[4]*Institute of Physics, Eötvös University, Pázmány Péter sétány 1/A, Budapest, 1117, Hungary*
[5]*Department of Physics, Bogazici University, 34342 Istanbul, Turkey*

We present *XMM-Newton*/EPIC observations of six merging galaxy clusters and study the distributions of their temperature, Fe abundance and pseudo-entropy profiles. For the first time, we focus simultaneously on the chemical and thermodynamic properties of the collided intracluster medium (ICM). When averaged out to r_{500}, the Fe distribution is found to be in excellent agreement with the average profile in typical non-cool-core clusters. In addition to showing a moderate central abundance peak, the Fe abundance flattens at large radii towards ∼0.2–0.3 $Z_\odot$. Although this distribution is in line with the idea that disturbed clusters originate from the merging of relaxed clusters, we find that in some cases, metal-rich and low entropy cool-cores can survive to major mergers. While we obtain a mild anti-correlation between the Fe abundance and the pseudo-entropy in the inner regions, no clear correlation is found at outer radii. This suggests that merging shocks are more efficient in increasing the pseudo-entropy of the ICM than in displacing and mixing metals therein. Together with the apparent uniformity of the average abundance at large radii, this is also the first hint toward the extension of the early enrichment scenario from cool-core and non-cool-core clusters to merging clusters as well.

The connection between triaxiality and cluster merging history

Iraj Vaezzadeh[1], Elke Roediger[1], Matthew Hunt[1]
[1]*E.A. Milne Centre for Astrophysics, University of Hull*

Galaxy clusters are a conduit between astrophysics and cosmology as they exist at the nodes of the filaments that constitute the cosmic web. Clusters grow by merging with their neighbours and as such can be used to develop our understanding of large-scale structure formation. By simulating merger events using hydrodynamical codes overlaid with N-body simulations of dark matter, we can gain insights into their role in the development of cluster morphologies observed in the Universe and how they trace the growth history of clusters. A number of clusters show a pronounced ellipticity in images of both their ICM atmospheres as well as their central BCG, e.g. Abell 2029 and Abell 2142. Such a projected ellipticity can arise from a cluster growing via merging with neighbouring clusters along well-aligned cosmic filaments as shown by cosmological simulations. By simulating such a merger series using a hydrodynamical code, we determine merger histories that create significant triaxiality in a cluster as well as the resilience of the triaxiality to off-axis mergers.

Broadband, spatially-resolved temperature constraints in galaxy clusters

Daniel Wik[1]
[1]*University of Utah*

While XRISM will provide high resolution calorimeter spectra of multiple galaxy clusters for the first time, the lack of a hard X-ray telescope reduces its potential science return compared to Hitomi. An extended bandpass to harder X-ray energies allows more sensitive continuum-based temperatures that can be compared to and combined with temperature measurements from line ratios, leading to the strongest constraints yet possible on multiphase gas, non-thermal emission, and the accuracy of plasma codes. We present a forward-modeling approach that allows XMM-Newton, Chandra, and NuSTAR data to be simultaneously fit in a spatially resolved way that accounts for differing and variable PSF sizes and spectral responses. The technique is demonstrated with observations of the Bullet cluster, Abell 2163, Abell 665, and Abell 2146 in order to spatially resolve and constrain the highest temperature regions (associated with cluster merger shocks) in these clusters. We will also discuss future work on the NuSTAR analysis of mosaics of the nearby Coma, Abell 2256, and Perseus clusters—prime targets of XRISM—that suffer from scattered light contamination. Lastly, a vision for incorporating XRISM data into this forward-modeling approach, and the potential scientific return for observations of extended sources of all types, will be presented.

Chapter 5

Plasma Codes

CPIPES - Collisional + Photo Ionization Plasma Emission Software

Miguel de Avillez[1]
[1] *Computational Astrophysics Group, Department of Mathematics, University of Evora, Portugal*

CPIPES (Collision + Photoionization Plasma Emission Software) traces the evolution of the ionisation structure and emission processes of optically thin plasmas. It can be used as a standalone software or coupled to any hydrodynamical and magnetohydrodynamical software tracing the dynamical evolution of the interstellar plasma. In particular it is being used to calculate the joint thermal and dynamical evolutions of the supernova and cosmic-rays driven interstellar medium.

The physical processes included in CPIPES are electron impact ionization, inner-shell excitation auto-ionization, radiative and dielectronic recombination (followed by cascades), charge-exchange reactions (recombination and ionization), continuum (bremsstrahlung, free- bound, and two-photon) and line (permitted, semi-forbidden, and forbidden) emission. The radiative model further comprises detailed calculations of the relative populations due to electron impact excitation and de-excitation, and spontaneous emission using up to a 70-levels model. The code further includes photoionization due to an external radiation field, and inner-shell photoionization due to cascades. In addition, Auger and Coster-Kronig photo-ejection of deep shell electrons is taken into account.

CPIPES includes thermal and non-thermal distributions of electrons and protons and is used to determine the ionization structure and emission of ionized plasmas with cosmic rays.

The Relativistic Hydrodynamics Adaptive Nested Mesh Code for IBM Power 9

Igor Kulikov[1]
[1] *Institute of Computational Mathematics and Mathematical Geophysics of SB RAS, Novosibirsk, Russia*

In this poster, the results of numerical simulations of relativistic hydrodynamics flows using the latest IBM Power 9 processors are presented. The numerical method implemented in the code is based on a combination of the Godunov method and Piecewise-Parabolic on Local Stencil method and extended for using nested adaptive mesh technologies. A relativistic hydrodynamic evolution of astronomical objects is performed on the node with IBM Power 9 on shared memory architecture. A new numerical method and parallel implementation for shared memory architectures are described in details. Studies of the code parallel implementation are presented. When using a regular mesh with an effective resolution of 512x512x512, 60x acceleration was obtained using 196 threads of IBM Power 9. When using a nested mesh with an effective resolution of 1024x1024x1024, 42x acceleration was obtained using 64 threads of IBM Power 9. When using a nested mesh with an effective resolution of 4096x4096x4096, 34x acceleration was obtained using 48 threads of IBM Power 9. The results of numerical modeling of relativistic hydrodynamics of jet galaxy formation are presented in poster.

Non-equilibrium ionization in mixed-morphology supernova remnants

Gao-Yuan Zhang[1,2], Adam Foster[2], Randall Smith[2], Jonathan Slavin[2], John ZuHone[2], Ping Zhou[3], Yang Chen[1]

[1]*School of Space Science and Astronomy, Nanjing University, 163 Xianlin Avenue, Nanjing 210023, P.R. China*

[2]*Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138 USA*

[3]*Anton Pannekoek Institute for Astronomy, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands*

Mixed morphology supernova remnants (MMSNRs) comprise a substantial fraction of observed remnants but their origin remains puzzling. Recently, a clue to their nature arose from X-ray evidence of recombining plasmas in some MMSNRs. Recent calculations of remnant evolution in a cloudy interstellar medium that included thermal conduction but not non-equilibrium ionization (NEI) showed promise in explaining observed surface brightness distributions but could not determine if recombining plasmas were present. We present numerical hydrodynamical models of MMSNRs in 2D and 3D including explicit calculation of NEI effects done via an efficient eigenvalue method. Both the spatial ionization distribution and temperature-density diagrams from the simulations show recombining plasmas created both by adiabatic expansion and thermal conduction, albeit in different regions. Features created by the adiabatic expansion stand out in the spatial and temperature-density diagrams, but thermal conduction also plays a role.

Simulated observations from XRISM, Athena, and Lynx with both spatial and spectral input from various regions will also be presented along with initial results on how well the underlying physics can be uncovered from spectral analyses.

Chapter 6

Plasma modelling and spectral fitting

The importance of the atomic history in time-dependent simulations of the interstellar gas

Miguel de Avillez[1,2], Dieter Breitschwerdt[2]
[1] *Computational Astrophysics Group, Department of Mathematics, University of Evora, Portugal*
[2] *Zentrum fur Astronomie und Astrophysik, Technische Universität Berlin, Germany*

The majority of the numerical models of the interstellar gas include a sink term in the energy equation through a tabulated cooling function (either calculated in collisional ionisation equilibrium or in non-equilibrium ionisation conditions). These simulations do not trace the time-dependent atomic history of the gas parcels. Hence, it is assumed that all gas parcels have exactly the same atomic history, which of course is not true. We present the latest developments in the subject pointing out the need for self-consistent calculations of the time-dependent dynamical and atomic evolution of the plasma and the consequences for the simulated x-ray emission.

Multi-temperature plasma and the spectroscopic-like temperature bias with the Athena X-IFU

Fabio Gastaldello[1], Mariachiara Rossetti[1], Silvano Molendi[1], Simona Ghizzardi[1], Sabrina De Grandi[2], Stefano Ettori[3], Dominique Eckert[4]
[1] *INAF-IASF Milan*
[2] *INAF-OAB Milan*
[3] *INAF-OAS Bologna*
[4] *University of Geneve*

Current X-ray observatories equipped with CCDs can not detect multi-temperature plasma when the temperature components are above 2 keV. This has important implications for the study of the thermal structure in galaxy clusters and groups especially when strong temperature gradients are present, such as in shock and cold fronts, or when plasma with different temperature components are co-spatial such as in cool cores. We will show the results of a series of idealized simulations with two temperature components to approximate the differential emission measure distribution of a multi-temperature plasma with the Athena X-IFU resolution to investigate how the scenario will change with the advent of a high resolution, high throughput calorimeter.

Numerical Simulation to Study Hard X-ray emission from solar corona.

Bheem Singh Jatav[1]
[1]*Department of physics, Sikkim University, Gangtok, Sikkim, India.*

In the present work, I have studied coherent structures and power spectrum for hard-X ray emission from corona by collapsing trap model (CTM). The numerical simulation has been carried out by pseudo-spectral method when the magnetic flux of current sheet considered as initial condition. The dimensionless model nonlinear dynamical equation has been derived from the compressible ideal kinematic MHD equation, which satisfies the modified nonlinear Schrödinger equation. The resulting coherent structures are of the complex nature and reaches to quasi-steady state. The associated power spectrum has also been studied. The CTM breaks the power spectrum and shows $k^{-4/3}$, $k^{-9/7}$ scaling. Observed results lead to the hard X-ray emission from corona and particle acceleration in solar flares.

Investigation of the NEI stellar cluster wind of NGC 3603

Wei Sun[1], Li Ji[1]
[1]*Purple Mountain Observatory, CAS*

The collection of OB stars in super stellar clusters (SSCs) is supposed to launch stellar cluster winds as the form of transonic flow shedding X-rays. However, in some cases the hot plasma may deviate from collisional ionization equilibrium (CIE), because the dynamical timescale is shorter than the ionization timescale for most species. We have developed a self-consistent physical model for stellar cluster winds based on combining a 1D steady-state adiabatic wind solution and a non-equilibrium ionization (NEI) calculation, as well as the state-of-art atomic database. We found that comparing to the CIE case, the line emission of several ions (e.g., O VIII, O VII) is enhanced due to delayed ionization, which alters the surface brightness of the soft X-ray band. Customized NEI model has also been confronted with the archived 500 ks Chandra observation of NGC 3603, the most prominent super stellar cluster in the Galaxy. Derived physical quantities such as the mass and terminal velocity are comparable to other empirical estimates.

Exploring the multi phase medium in MKW08: from the central active galaxy up to cluster scales

Aysegul Tumer[1,2], Francesco Tombesi[2,3,4,5], Hervé Bourdin[2], Enise Nihal Ercan[1], Massimo Gaspari[6,7], Roberto Serafinelli[8]

[1]*Department of Physics, Bogazici University, Bebek, 34342 Istanbul, Turkey*

[2]*Department of Physics, University of Rome "Tor Vergata", Via della Ricerca Scientifica 1, 00133 Rome, Italy*

[3]*Department of Astronomy, University of Maryland, College Park, MD 20742, USA*

[4]*NASA/Goddard Space Flight Center, Code 662, Greenbelt, MD 20771, USA*

[5]*INAF Osservatorio Astronomico di Roma, Via Frascati 33, 00078 Monteporzio Catone, Italy*

[6]*Department of Astrophysical Sciences, Princeton University, 4 Ivy Lane, Princeton, NJ 08544-1001, USA*

[7]*Lyman Spitzer Jr. Fellow*

[8]*INAF Osservatorio Astronomico di Brera, Via Brera 28, 20121 Milan, Italy*

In this work, using archival XMM-Newton and Chandra X-ray observations, we investigate the properties of the intra-cluster medium of the non-cool core galaxy cluster MKW08 (z=0.027) and of itsBCG, NGC 5718, along with the properties of the interface region of the galaxy and cluster media.The data set allowed us to explore the full range of physical scales from the AGN up to 400 kpc. Imaging analyses show a point-source excess at the location of the BCG and presence of an AGN is confirmed by the X-ray spectral analysis with power-law index =1.8 at the center of NGC 5718.We find evidence for a thermal emission component possibly at the interface region between the ISM of the BGC and the CGM/ICM.Although MKW08 was classified as a noncool core galaxy cluster, its temperature profile shows an increase from 1keV to 4 keV in this transition region, resembling that of a cool core.By fitting double beta-model and its individual components to cluster surface brightness profile, we were able to demonstrate the power-law contribution near the cluster center. The method presented in this work will have important implications for the upcoming missions such as XRISM and Athena.

Chapter 7

Miscellaneous

Thermal emission from bow shocks I: 2D Hydrodynamic Models of the Bubble Nebula

Samuel Green[1,2], Jonathan Mackey[1]
[1] *Dublin Institute for Advanced Studies*
[2] *University College Dublin*

The Bubble Nebula (or NGC7635) is a parsec-scale seemingly spherical wind-blown bubble around the relatively unevolved O star BD+602522. The small dynamical age of the nebula and significant space velocity of the star suggest that NGC7635 might be a bow shock. We have run 2D hydrodynamic simulations to model the interaction of the central star's wind with the interstellar medium (ISM). Synthetic Halpha and 24 μm emission maps predict the same apparent spherical bubble shape with observations. Synthetic maps of soft (0.5-2keV) and hard (2-10keV) X-ray emission show that the brightest region is in the wake behind the star and not at the bow shock itself. The unabsorbed soft X-rays have luminosity $\sim 10^{32} - 10^{33}\, erg\, s^{-1}$. The hard X-rays are fainter, luminosity $\sim 10^{30} - 10^{31}\, erg\, s^{-1}$, and maybe too faint for current X-ray instruments to successfully observe. Our results imply that the O star creates a bow shock as it moves through the ISM and in turn creates an asymmetric bubble visible at optical and infrared wavelengths, and predicted to be visible in X-rays. The dense ISM surrounding BD+602522 and its strong wind suggest it could be a good candidate for detecting non-thermal emission.

Testing the Theory of Wind-Blown Bubbles with the Bubble Nebula - NGC 7635

Martin A Guerrero[1], Jesus A Toala[2], Helge Todt[3], Laurence Sabin[4], You-Hua Chu[5], Gerardo Ramos Larios[6], Lida Oskinova[3]
[1] *Instituto de Astrofísica de Andalucía, IAA-CSIC (Spain)*
[2] *Instituto de Radioastronomía y Astrofísica, IRyA-UNAM (Mexico)*
[3] *Institut für Physik und Astronomie, Universität Potsdam (Germany)*
[4] *Instituto de Astronomía, IA-UNAM (Mexico)*
[5] *Institute of Astronomy and Astrophysics, Academia Sinica, ASIAA (Taiwan)*
[6] *Instituto de Astronomía y Meteorología, Universidad de Guadalajara (Mexico)*

We present a multi-wavelength study of NGC 7635, the iconic Bubble Nebula around its progenitor O6.5 III star BD+60°2522. Our *XMM-Newton* EPIC observations detect BD+60°2522 as a bright X-ray source, but no extended soft X-ray emission is detected as in wind-blown bubbles around evolved massive stars. Using IR and optical images and high-dispersion echelle spectra of NGC 7635, the lack of X-ray emission is interpreted in terms of recent radiation-hydrodynamic simulations of the interaction of the stellar wind of BD+60°2522 with the surrounding H II region S 162.

Diffuse X-ray observations towards high ecliptic latitude fields: Variation of heliospheric SWCX signal throughout the solar cycle

Dimitra Koutroumpa[1], Steve Snowden[2], Kip Kuntz[3], Michael Collier[2], Massimiliano Galeazzi[4], Dan McCammon[5], Randall Smith[6]
[1]*LATMOS-IPSL, CNRS, Université Paris-Saclay, Sorbonne Université, Guyancourt, France*
[2]*NASA/Goddard Space Flight Center, Greenbelt, MD, USA*
[3]*Henry A. Rowland Dept. of Physics and Astronomy, The Johns Hopkins University, Baltimore, MD, USA*
[4]*Physics Dept., University of Miami, Coral Gables, FL, USA*
[5]*Dept. of Physics, University of Wisconsin, Madison, WI, USA*
[6]*Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA*

We present a series of high-latitude observations to study the variation of solar wind charge exchange (SWCX) signal throughout the solar cycle. 20 XMM-Newton and Suzaku observations of the South Ecliptic Pole (SEP), North Ecliptic Pole (NEP) and the Hubble Deep Field North (HDFN) in the 2001-2009 period are analyzed. Most of them look through the interplanetary He focusing cone at different solar periods, where we expect enhanced SWCX emission due to the increased neutral density. The northern fields yield lower line fluxes than the SEP, since the cone is centered at -5° south. However, there is no conclusive detection of the cone spatial signature. Furthermore, the decline of solar activity between 2001 and 2009 was expected to produce a drop in SWCX line fluxes during the 2009 observations compared to the ones between 2001 and 2006. The ACE satellite measures a strong decrease of the O7+ particle flux, and heliospheric models predict a consequent drop in SWCX line fluxes, but there is no obvious decrease in the measured X-ray line flux. The measured X-ray flux seems to correlate best with the solar proton flux, which remains relatively stable throughout the cycle. We discuss possible explanations and offer some perspectives.

Hot Bubbles: Extended X-ray Emission in Planetary Nebulae

Rodolfo Montez[1], ChanPlaNS Collaboration[1]
[1]*Center for Astrophysics | Harvard & Smithsonian*

The death of a sun-like star is marked by the iconic planetary nebula (PN) phase, during which mass lost during the star's asymptotic giant branch evolution is shaped into beautiful and bright shells of ionized gas. The ionized shells of many PNe are filled with hot post-shock plasma that is detectable only in X-ray emission. These extended plasmas, so-called hot bubbles, are resolved by both Chandra and XMM-Newton observations. The Chandra Planetary Nebulae Survey (ChanPlaNS) embarked on a volume-limited survey of nearby PNe that characterized the plasma properties and evolution of hot bubbles. The resulting observational characterization of hot bubbles has driven theoretical efforts to better understand these chemically-enriched plasmas. More recent studies have demonstrated the power of spatially-resolved X-ray studies of PN hot bubble emission for the rare examples of high count sources. In this presentation, I present an overview of our present understanding of PN hot bubbles, as well as likely future observational and theoretical research directions.

Searching for hot WHIM

Jukka Nevalainen[1], Elmo Tempel[1], Jussi Ahoranta[2], Alexis Finoguenov[2]
[1] *Tartu University*
[2] *Helsinki University*

I discuss the recent results on detecting and modelling the X-ray absorption signals from the Warm Hot Intergalactic Medium WHIM using high resolution spectrometers RGS and LETG onboard XMM-Newton and Chandra. I emphasise the X-ray search for the hottest WHIM at the locations of the FUV-detected warm WHIM. I discuss the detection of the Cosmic Web filaments, the expected reservours of the hot WHIM, in the Sloan Digital Sky Survey SDSS. I describe our efforts to use the SDSS filament info as WHIM finding maps for the future instruments onboadr ARCUS, eRosita and ATHENA.

Constraints on mixing angle for a sterile neutrino dark matter model using XMM-Newton observations of dwarf spheroidal galaxies

Sara Saeedi[1], Denys Malyshev[1], Manami Sasaki[2], Andrea Santangelo[1]
[1] *Institute of astronomy and astrophysics, University of Tuebingen, Germany*
[2] *Dr. Karl Remeis Observatory and ECAP, Universität Erlangen-Nürnberg,Germany*

The dwarf Spheroidal galaxies (dSphs) are known to be one of the most dark matter dominated objects, which in a combination with low astrophysical background make them one of the best targets for dark matter studies. In this work we present the results of the search of a dark matter decay line in XMM-Newton spectra of nine dSphs (Draco, Carina, Fornax, Leo I, Willman, Ursa Minor, Ursa major II, NGC 185, Sculptor) in 1-10 keV energy band. The total net exposure time of $\sim$3.5 Msec of the EPIC-cameras data significantly exceeds the exposure used for previous searches for a keV-scale decaying dark matter. This allowed us to improve the existing limits on a dark matter decay width as well as improve the constraints on a mixing angle for a sterile neutrino dark matter model.

Warm-Hot Intergalactic Medium in the EAGLE simulation

Toni Tuominen[1], Jukka Nevalainen[1]
[1] *Tartu Observatory, University of Tartu, Estonia*

Based on the EAGLE simulations, I discuss the temperature distribution of the baryons within the filaments of the Cosmic Web. In particular, I characterize the properties of the hottest Warm-Hot Intergalactic Medium (WHIM), corresponding to temperatures in the range of log T(K)=5.5-7. With current instruments, observations of the diffuse intergalactic medium at these temperatures are extremely challenging. Thus, it is to be expected that a significant portion of baryons remains undetected. In this sense, the hot WHIM may be a candidate to the cosmological missing baryons problem. In order to bypass the observational difficulties, I use baryonic data from the EAGLE simulation in addition to a filament finder. This allows us to locate the spatial distribution of the hot WHIM in the large scale structure of the Universe. This distribution is then analytically modeled to aid future X-ray observations, as the regions of interest can be narrowed down.

Name Index