INTEGRAL 20 Years
"Two Decades of High-Energy Astronomy with INTEGRAL"
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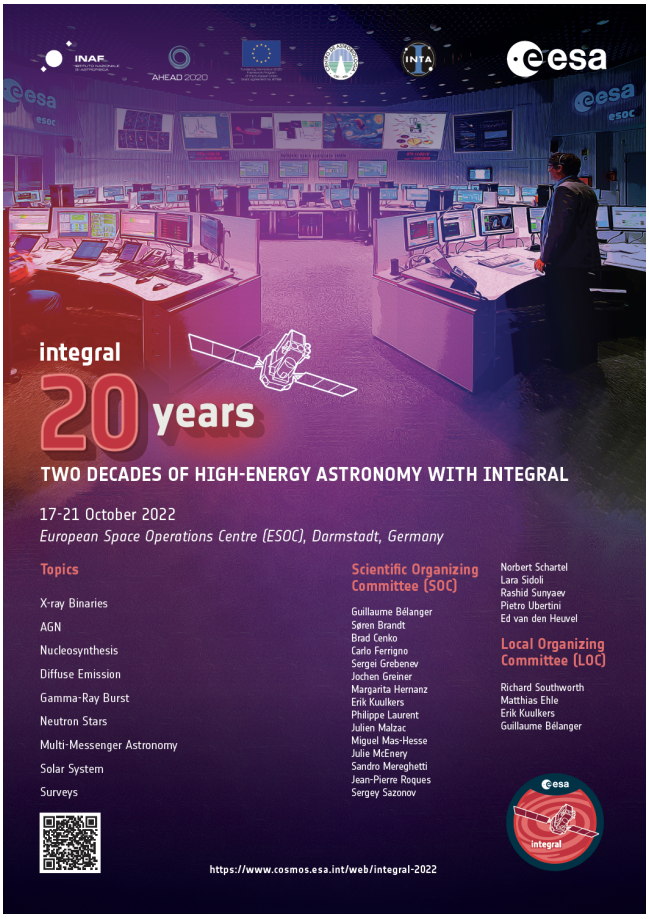
Programme & Abstracts



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Oral Presentations

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Lorenzo Amati

Cosmology and multi.messenger astrophysics with next generation GRB missions

Gamma-Ray Bursts constitute one of the most fascinating and relevant phenomena in modern science, with strong implications for several fields of astrophysics, cosmology and fundamental physics. Indeed, the huge luminosity, the redshift distribution extending at least up to z$\sim$10 and the association with the explosive death of very massive stars make long GRBs (i.e., those lasting up to a few minutes) potentially extremely powerful probes for investigating the early Universe (pop-III stars, cosmic re-ionization, SFR and metallicity evolution up to the 'cosmic dawn') and measuring cosmological parameters. The combination of extreme distances, the huge number of photons emitted over about three orders of magnitude in photon energy and the variability down to few ms makes these phenomena also a uniquely powerful and promising tool for performing tests of fundamental physics like Lorentz Invariance Violation (LIV) with unprecedented accuracy. At the same time, as demonstrated by the GW170817 event, short GRBs (lasting no more than a few s) are the most prominent electromagnetic counterpart of gravitational-wave sources like NS-NS and NS-BH merging events, and both long and short GRBs are expected to be associated with neutrino emission. My review will include the status, concepts and expected performances of space mission projects (e.g, THESEUS, Gamow Explorer) aiming at fully exploiting these unique potentialities of the GRB phenomenon, thus providing an ideal synergy with the large e.m. facilities of the future like LSST, ELT, TMT, SKA, CTA, ATHENA in the e.m. domain, advanced second generation (2G++) and third generation (3G) GW detectors and future large neutrino detectors (e.g., Km3NET).

Jacqueline Beechert

From balloon to satellite: Measuring Galactic Al-26 with the Compton Spectrometer and Imager

The Compton Spectrometer and Imager (COSI) is a 0.2–5 MeV Compton telescope designed for spectroscopy, imaging, and polarimetry. Like INTEGRAL SPI, the heart of COSI is comprised of high-purity germanium detectors with excellent energy resolution. COSI was originally developed as a balloon-borne instrument which flew for 46-days on a NASA superpressure balloon in 2016. The flight was a scientific and technological success: COSI detected and imaged the Galactic positron-electron annihilation excess at 511 keV, detected and placed an upper limit on the polarization of GRB160530A, detected the Crab nebula, and in a recent analysis, measured the 1809 keV decay signature of radioactive Galactic Al-26 with 3.7σ significance. The Inner Galaxy flux of Al-26 is reported as (8.6 $\pm$ 2.5) x 10^{-4} ph/cm^2/s. This presentation will detail the Al-26 analysis, compare results to those from SPI, and outline the expected performance of COSI as a NASA Small Explorer satellite mission, slated for launch in 2026.

G. Belanger

The development of the INTEGRAL Science Legacy Archive

The INTEGRAL observatory has been in operations since its launch in October 2002. During these more than 20 years in operations, data archiving and distribution has been the exclusive responsibility of the INTEGRAL Science Data Centre. With the end of operations, this responsibility shifts to ESA. The development of this legacy archive began at ESA's European Space Astronomy Centre in 2018, and with the basic infrastructure and UI framework in place, followed a collaboration with several members of the instrument teams to build the science products that would be used to provide the science community the ability to visually explore the rich data set from all the instruments on INTEGRAL: IBIS, SPI, JEM-X, and OMC. We will describe the main challenges involved in its development, and present the current version of the INTEGRAL Science Legacy Archive.

Tomaso Belloni

Future Perspectives on Black-Hole Binaries

The amount of observational data from black-hole binaries is now increasing at a fast rate, thanks to the high-energy missions currently available. I will outline the current situation, focusing onto the most recent developments, and attempt to extrapolate both to the next future and to the time of future missions more distant in time.

Joanna Berteaud

Investigating Primordial Black Hole Dark Matter with 16 years of SPI data

Dark matter (DM), while accounting for more than 68% of the energy density of the Universe, still keeps its nature secret. Many candidates have been put forward, sharing one similarity: being massive, in order to reproduce the observed gravitational effects attributed to DM. The higher end of the mass scale discloses non-particle theoretical candidates: Primordial Black Holes (PBHs). Microlensing and gravitational waves, among other probes, already helped constraining the PBH contribution to DM for masses from 10^{22} to 10^{35} g, but the asteroid mass range, from 10^{17} to 10^{22} g, remains mostly unconstrained. In this talk, I will present how the diffuse Galactic MeV emission, newly determined by Siegert et al. (2022) from 16 years of SPI data, helped us stretching up the constraints into the asteroid mass range. Using the predictions for black hole evaporation, we demonstrated that PBHs cannot account for all the DM if their mass is smaller than 4x10^{17} g.

Björn Biltzinger

Time-Resolved Spectral Catalogue of INTEGRAL/SPI GRBs

Since its launch in 2002 INTEGRAL/SPI has observed many gamma-ray bursts (GRBs). We used all available data up to the end of 2021 to create a time-resolved spectral catalogue of SPI GRBs for both empirical models and a physical synchrotron model. We compare the parameter distributions from the empirical model catalogue to the ones from Fermi/GBM and see that INTEGRAL/SPI can constrain GRB spectra well only over a much narrower peak energy range, compared to Fermi/GBM. From the physical synchrotron model catalogue we can support the recent results with Fermi/GBM data that this model is capable of fitting most GRB spectra well and that it results in a broad variety of cooling regimes in GRB spectra. In addition we checked for GRBs in the INTEGRAL/SPI data that have not been reported before and can identify two new GRBs. In this talk I will present the methods we used to create the catalogues and identify the two new GRBs as well as show the implications our results have on theoretical GRB models but also possible future mission planing of GRB detectors.

Enrico Bozzo

Exploring the donor wind environment in high-mass X-ray binaries

Wind-fed supergiant X-ray binaries are precious laboratories not only to study accretion under extreme gravity and magnetic field conditions, but also to probe still highly debated properties of massive star winds. These includes the so-called clumps, originated from the inherent instability of line driven winds, and larger structures. In this talk, we report on the results of monitoring campaigns that with both XMM-Newton and the Swift Neil Gehrels observatory. Data collected with the EPIC cameras allow us to carry out a detailed hardness ratio-resolved spectral analysis that can be used as an efficient way to detect spectral variations associated to the presence of clumps. Long-term observations with the XRT on-board Swift evenly sampling the X-ray emission of supergiant X-ray binaries over many different orbital cycles, are exploited to look for the presence of large scale structures in the medium surrounding the compact objects. These can be associated either to corotating interaction regions or to accretion/photoionization wakes, as well as tidal streams. All results obtained for our sample are discussed in the context of wind-fed supergiant X-ray binaries and shall ideally serve to optimally shape the next observational campaigns aimed at sources in the same classes.

Gabriele Bruni

Stranger things in the INTEGRAL sky: wobbling jets, neutrinos, and binary black holes

The identification of neutrino sources is one of the main challenges in nowadays astrophysics. Available models point to jets as the most likely neutrino site, and in particular the interaction of material in precessing jets. So far, only a clear neutrino association has been obtained, corresponding to blazar TXS 0506+056. The ANTARES collaboration has recently performed a correlation of the neutrino events collected between 2007 and 2018 with several AGN catalogues. They found the presence of 2 events located at less than 0.5 degrees from the radio galaxy 3C403, detected also in hard X-rays by INTEGRAL. From an inspection of archival data from the past decades, we found a discrepancy of the jet position angle on different scales, including hints of an S-shape morphology, suggesting precession. This is accompanied by a strong variability both in radio and X-rays. This could turn out to be the first radio galaxy clearly associated with a neutrino event. In addition to this result, I will discuss some of the most peculiar INTEGRAL AGN studied during the past years: two X-shaped giant radio galaxies showing extreme jet re-orientation, and a recent candidate binary black hole for which coalescence is foreseen during the next couple of years.

J. Michael Burgess

3ML: The multi-mission maximum likelihood framework

As the multi-messenger era is now fully active, it is crucial that the community has a framework within which to analyze data from multiple messengers, wavelengths, and instruments in a statistically robust, common way. 3ML (https://threeml.readthedocs.io) provides an abstract, plugin-based data interface for instruments to combine analysis through each instrument's own unique likelihood. Users and instrument teams can create or use existing plugins to interface their data to a plethora of Bayesian and optimization packages in a uniform way. Analysis results are reported and stored in portable file formats that allow for the sharing and replication of results in a way that allows observers to produce robust scientific results that the community can interpret. 3ML currently supports, via standard plugins many ground and space-based observatories as well as being the analysis tool for some collaborations (HAWC, XIPE, Fermi-LAT, POLAR, GECAM)

J. Michael Burgess

Exploring the WHIM via GRB afterglows and Bayesian hierarchical modeling

The possible existence of a diffuse WHIM absorber in the Universe can be explored by looking at the soft X-ray absorption in gamma-ray burst afterglows. However, the slight change in the amount of absorption induced by a WHIM component can be difficult, to distinguish in any individual spectrum. By using hierarchical Bayesian modeling, we can combine the data from multiple observed X-ray afterglows by simultaneously fitting their spectra together and using their joint information to probe properties of the WHIM. This approach also allows us to constrain properties about the population GRB host galaxy nH distribution and emission spectral properties in a way that is impossible via the typical 'stacking of data' approach. Moreover, these types of models are widely applicable to the study of other X-ray populations.

Eric Burns

Gravitational Waves and Gamma-rays in the LIGO, Virgo, and KAGRA O4 and O5 Observing Runs

The first multimessenger detection of a neutron star merger was discovered by LIGO, Virgo, Fermi, and INTEGRAL in 2017, initiating one of the largest observing campaigns in astronomy. The gamma-ray and gravitational wave observations measured the speed of gravity and proved binary neutron star mergers as a source of gamma-ray bursts. Their localization enabled identification of the afterglow, kilonova, and host galaxy, providing measurements on the neutron equation of state, the origin of heavy elements, and demonstrated the use of standard sirens for cosmology. In the O4 observing run, beginning next year, we expect approximately one joint detection through gamma-rays, and multiple joint detections per year beginning in O5 in early 2026. We will highlight the critical role of INTEGRAL in this era, improvements in accessibility and prompt annuli generation, and, time permitting, discuss other potential sources of gamma-rays and gravitational waves.

Francesca Capel

Evaluating multi-messenger coincidences in the context of astrophysical source populations

Several tentative associations between high-energy neutrinos and astrophysical sources have been recently reported, but a conclusive identification of these putative neutrino emitters remains challenging. We investigate the context of proposed individual source-neutrino associations via Monte Carlo simulations of source populations. In particular, we focus on the coincidences between neutrino events and gamma-ray blazar flares, motivated by the IC170922A/TXS 0506+056 observation. We show that the assumptions required to find a significant association lead to an extreme overproduction of energetic neutrinos from the population unless the gamma-ray-neutrino connection is weak or only a small subset of blazars contribute to the neutrino flux. Our results highlight the importance of the likelihood when searching for multi-messenger connections and the issues with simple spatial association approaches that are disconnected from physical models. As such methods are widely used, we motivate a closer connection between theory and data in future association analyses relevant for INTEGRAL and the broader multi-messenger community.

Bertrand Cordier

Future Perspectives of GRBs in the next decade

The science of gamma-ray bursts has experienced a boost in interest with the association of a gravitational wave source with a short gamma-ray burst GRB170817. The scientific interest of the coming decade is not exclusively in the distant universe but will focus on the local universe with the detection of sub-luminous bursts. In this talk, I will present in detail the SVOM mission that will be launched in October 2023 but I will also mention the Chinese missions Einstein Probe and GECAM. These three missions, potentially contemporaneous with the 04 and 05 gravitational wave detection campaigns, should allow significant advances in our understanding of the transient sky.

Nathalie Degenaar

Low-mass X-ray binaries: Future Missions

Low-mass X-ray binaries (LMXBs), neutron stars or a black holes devours gas from a companion star, are key to a variety of science questions in modern astrophysics. In this talk I will review some of the big open questions related to X-ray binaries and what advances new and future observatories will bring.

Roland Diehl

Cosmic nucleosynthesis and gamma-ray lines

Cosmic nucleosynthesis had been one of INTEGRAL's major science targets. The SPI spectrometer delivered important measurements, both from targets of opportunity in the form of stellar explosions and their short-lived radionuclides, and from cumulative emission of long-lived radioactive isotopes. We review the lessons learned on explosive nucleosynthesis and supernova explosions, and massive stars related to core-collapse supernovae, from the measurements of the lines from the ^{56}Ni decay chain, of ^{44}Ti decay, and of diffuse emission in the lines from ^{26}Al and 60Fe. We also address how gamma-ray results relate to other measurements on explosions and radioactive ashes thereof.

Carlo Ferrigno

A Gallery of INTEGRAL high-level products

The INTEGRAL Science Data Centre provides software to analyse the row data as well as an online platform, called MMODA that allows to retrieve image, spectra, and lightcurves through a web interface or a flexible python interface. Building upon this tool, we have created a Gallery for valuable products that can be accessed from several points of view. Here are the main ones: - For each satellite revolution, we provide a mosaic image of each observation that is performed both from Near Real time data and from consolidated ones. We compute the flux of every significantly detected source and extract its spectrum; - For each relevant source we provide

a mission-long light curve in at least one standard energy band and a global spectrum, as well as all other products that are available in our database; - For each observing period in which data are available, we provide all the products. All images can be actively inspected by the user and the corresponding fits files can be easily downloaded. The purpose of this talk is to illustrate the prototype of this gallery with a few products available in order to gather comments and wishes by the user before the mass production of final products. The gallery interface, the products, and the code to generate them will be open and can be run by any interested user, building a legacy product that will remain available to the community.

Diego Götz

GRBs with INTEGRAL

I will review the contributions of INTEGRAL to the Gamma-Ray Bursts (GRBs) field during the last 20 years. Thanks to the use of the SPI-ACS INTEGRAL contributes to the all sky survey of gamma-ray transients, participates to the InterPlanetary Network (IPN) localizations, and has plays a crucial role also in multi-messengers observations. The Integral Burst Alert System has allowed for near real time precise localizations of GRBs and subsequent multi-wavelength follow-up. Finally the polarization measurements obtained by IBIS and SPI contributed to open a new window on GRB science. The scientific highlights will be presented in this talk.

Gourab Giri

Understanding the origin of peculiar jetted winged galaxies using multiwavelength modeling

A small fraction of the ejected jets from Active Galactic Nuclei (AGN) are found to be deviating from their intended path, creating peculiar winged radio galaxies. Some of these sources raise X-shaped morphology by bending the jet in opposite direction producing inversion symmetric structures. Because of this peculiarity, the formation mechanism of such sources is still debated, with the debate relating the origin to the asymmetric ambient medium or any complex activities occurring in the AGN. As more low-frequency radio observations and high-resolution X-ray observations become available, unraveling the macro-physics responsible for their formation is becoming increasingly difficult because of the complexity observed associated with them. In this regard, we have performed numerical simulations using hybrid Eulerian-Lagrangian framework and the Adaptive Mesh refinement techniques to shed light on the origin and evolution of these galaxies by better capturing the underlying micro-physical processes. Use of these updated approaches has helped us understand the unusual spectral properties observed in these sources, which will be showcased along with their correlation to the diffusive shock acceleration mechanism. We will also discuss how the formed morphology varies based on viewing angle and different formation scenarios. Furthermore, we will showcase the X-ray map obtained of the ambient cluster medium of such galaxies from our simulations and what information they share while determining the macro-physics of these galaxies. Finally, we will elaborate a little about how our results relate to the upcoming low-frequency radio and X-ray missions and where we are heading regarding these unusual sources.

Jason Hessels

Pinpointing fast radio bursts in space and time

In the past decade we have started to explore extragalactic and intergalactic space using millisecond-duration radio flashes called 'fast radio bursts' (FRBs). These cosmological signals are surprisingly abundant: there is likely an FRB occurring somewhere on the sky at least once every minute. They are also unique probes of the otherwise invisible material between stars and galaxies. But what is producing them? Thanks to a new generation of wide-field radio telescopes, several FRBs per day are now being discovered. Novel high-time-resolution observations using radio interferometers are also pinpointing FRB locations and providing host galaxy associations. More than a decade since the discovery of the famous 'Lorimer burst', we are making rapid progress in our understanding of the enigmatic FRB phenomenon. In this talk, I will briefly review the status of the field, highlighting some of the latest discoveries and what they have taught us. At the same time, recent discoveries are showing us that we have still only scratched the surface in terms of the vast parameter space we can potentially explore. Expanding our exploration for FRB-like signals to an even wider range of timescales, luminosities and event-rates will allow us to discover new types of extreme astrophysical phenomena – some of which are likely to have high-energy counterparts.

Elisabeth Jourdain

Black-Hole Binaries with INTEGRAL

Black hole binaries (BHB, often identified with microquasars) are among the brightest sources emitting above ∼10 keV up to a few hundreds keV. Hard X-ray observations are thus crucial to understand not only the high energy emission, but also the overall functioning of these sources. In this energy domain, INTEGRAL is the first mission to provide accurate energy and timing information as well as polarimetric measurements. All this has changed our vision of the mechanisms of energy transfer at work in these objects. In particular, the INTEGRAL observations established that several components coexist above ∼20 keV, and that the jet usually observed in radio can contribute significantly beyond ∼100 keV. Nevertheless, spectral and temporal behaviours observed among sources, whether persistent or transient, are highly diverse, which remains to be understood. After 20 years of operation, the database built from INTEGRAL observations is exceptional and stimulates the quest for a unified model able to reproduce the different characteristics with a minimum number of ingredients. We will summarize the main results obtained by INTEGRAL and describe how they can help to constrain the proposed scenarios.

Bidzina Kapanadze

Joint INTEGRAL-Swift Target of Opportunity Observations of the Extreme TeV-Detected Blazar Markarian 501

The TeV-detected nearby ($z = 0.034$) blazar Markarian 501 is prominent by the extreme X-ray and TeV-band variability on the diverse timescales ranging from years down to a few minutes. Since 2021 March, we observe a significantly enhanced X-ray activity of the source compared to the previous years (and comparable to the exceptional flaring behaviour shown during 2014–2015). Apparently, the source undergo variations in the baseline X-ray level on timescales of several years, which should be related to the enhanced jet collimation rate in some epochs triggered by some longterm instable processes in the accretion disc at the central supermassive black hole. A general high 0.3–10 keV level is accompanied by short-term flaring activity on timescales of 2-3 weeks, possibly triggered by the instable processes occurring in the relativistic jet closely aligned to our line-of-sight. During those instances, the X-ray spectra frequently are very hard with the photon index at 1 keV $a<1.80$, the position of the synchrotron SED peak sometimes located beyond 10 keV and the unabsorbed 0.3–10 keV flux higher than 2×10^{-10} erg/cm^2/s. In such a situation, we are able to trigger the INTEGRAL Target of Opportunity observations (TOOs) simultaneously with the densely-sampled Swift campaign. Such joint effort yielded the INTEGRAL detections of Markarian 501 with 3–5σ significances and extension of the synchrotron SED towards the highest X-ray frequencies. These results make us capable to model the observed SED with higher accuracy and extract more information about the physical conditions in the blazar emission zone.

Roman Krivonos

Census of hard X-ray sources across the entire sky as a Legacy of the INTEGRAL mission

The INTEGRAL hard X-ray surveys have proven to be of fundamental importance. Over two decades, INTEGRAL has completed its all-sky survey and mapped the Galactic plane with unprecedented sensitivity thanks to large field of view, excellent performance and long-term stability of the IBIS imager. Deep hard X-ray surveys of the whole Milky Way on a time scale of a year are beyond the capabilities of past and current narrow-FOV grazing incidence X-ray telescopes. Taking advantage of the whole data archive, a survey of hard X-ray sources has been recently conducted, providing the catalog of thousand Galactic and extragalactic hard X-ray emitters of different nature. In two decades of operation, the INTEGRAL observatory has provided the triggers for many follow-up campaigns from radio frequencies to gamma-rays. The INTEGRAL census of hard X-ray sources across the entire sky will without question be included in the annals of X-ray astronomy as one of the mission's significant contribution to our understanding of the hard X-ray sky. This work is supported by the Russian Science Foundation grant 19-12-00396.

Lucien Kuiper

Rotation-powered pulsars in the soft- and medium energy gamma-ray bands

In this review the current research status is presented of rotation-powered pulsars emitting in the soft- and medium energy gamma-ray bands (20 keV – 30 MeV). It starts with an historical overview showing the results obtained during the CGRO- and (early) RXTE missions (1991–2000). Next, the INTEGRAL contributions in this field are highlighted, followed by a summary of up-to-date results obtained from observations by NuSTAR (3–79 keV), Fermi GBM NaI/BGO (20 keV–30 MeV), Fermi LAT (>30 MeV), and other high-energy instruments using timing models based on (mainly) NICER (0.3–10 keV) monitoring observations. In particular, the detection of pulsed MeV emission from AX J1838.0−0655 and PSR J1813−1246 in Fermi GBM-BGO will be reported on. Finally, the prospects for pulsar research at ∼20 keV–100 MeV energies are discussed.

Jan Lommler

Event classification in Compton-Pair telescopes using Convolutional Networks

Low to medium energy gamma rays are shielded by the Earth's atmosphere and cannot be measured with on-ground facilities. Satellite based gamma-ray astronomy relies on Compton scatter and Pair creation as measurement channels. Among the biggest challenges are the poor signal to background ratio due to low signal fluxes from cosmic sources and the high background rates even in the comparatively moderate environment of Low Earth Orbits. An efficient event tagging reduces signal losses by preventing type-mismatching applications of reconstruction algorithms (e.g. performing a Compton reconstruction on a Pair event) and signal pollution (distinguishing events originating from background sources). We explore the feasibility of Deep Convolutional Neural Nets in the context of event classification for Compton-Pair telescopes on the example of the e-ASTROGAM design proposal.

Alexander Lutovinov

Three years of a hard X-ray sky

To date the Mikhail Pavlinsky ART-XC telescope has carried out four full all-sky surveys, as well as a significant number of observations of the most interesting X-ray objects and regions of the sky. During last several months the telescope is performing observations of our Galaxy aiming to most detailed and deep map of the Galaxy in hard X-rays. An overview of the results obtained with ART-XC will be briefly presented. A particular attention will be paid to the discovery and study of the nature of new galactic objects though the multiwavelength campaigns. This work is supported by the Russian Science Foundation grant 19-12-00423.

Angela Malizia

INTEGRAL/IBIS AGN: deeper on the Galactic plane and wider beyond

Over these 20 years, INTEGRAL has allowed great progress in the AGN science, leading to a deep knowledge of both their population in the sky and the physical mechanisms responsible for their emission on the entire electromagnetic spectrum. In particular, INTEGRAL data have allowed to characterize AGN spectra at high energies, to investigate their absorption properties and to test the AGN unification scheme through a multiwavelength approach. In this review I will summarize the main results obtained so far, highlight INTEGRAL's contribution to AGN science for each class of AGN and present the last update of the INTEGRAL AGN catalogue. Finally, I will show new perspectives, connecting INTEGRAL's science with that at other wavelengths and in particular in the GeV/TeV regime which is still poorly explored.

Silvia Martínez-Nuñez

High Mass X-ray Binaries as seen by INTEGRAL in the last two decades

The INTEGRAL mission has played a principal role in the comprehension of high mass X-ray binary (HMXB) systems in the last two decades. In this invited talk, I will present some of the most relevant studies performed using INTEGRAL data for this type of systems, taking as a baseline the extended review paper of Kretschmar et al. (2019). The most significant studies include: population studies performed thanks to the mission all-sky surveys; the discovery of many of the most interesting sources; and a few unexpected results for the different classes of HMXRB. To conclude the talk, I will briefly mention some future facilities in the high-energy domain that could contribute to solving some of the open questions addressed by INTEGRAL studies.

Sandro Mereghetti

IBAS contributions to the study of GRBs, Magnetars, FRBs and multimessenger astrophysics

Thanks to the implementation of an INTEGRAL Burst Alert System (IBAS), INTEGRAL has been the first gamma-ray satellite to provide arcminute localizations for transient events in near real time (typically within few tens of seconds). I will review the main contributions given by IBAS to the study of gamma-ray bursts and soft gamma-ray repeaters, as well as the most recent results concerning the counterparts of gravitational wave events and Fast Radio Bursts.

Ilya Mereminskiy

Searching for new populations of X-ray transients

The Mikhail Pavlinsky ART-XC telescope is ideally suited for sensitive wide-field X-ray surveys covering tens to hundreds square degrees per day. This allows us to search for new populations of X-ray transients, that are too weak to be discovered by all-sky monitors and too rare to be serendipitously found by other grazing-incidence mirror X-ray telescopes. Most of these transients are Galactic X-ray binaries of different classes that we are catching during active episodes.

Manuela Molina

INTEGRAL at 20: still finding peculiar AGN

Since its launch in October 2002, INTEGRAL has surveyed the high energy sky with unprecedented sensitivity, discovering many high energy emitting sources of many different kinds. Among these, AGN are one of the best sampled populations studied by INTEGRAL, also making up a large fraction of the detected sources. In this contribution I will present the latest results on a small sample of peculiar, newly detected AGN, included in the latest INTEGRAL AGN catalogue. Broad-band spectral analysis, using INTEGRAL data in combination with other soft and hard X-ray instruments provides an insight on the physical characteristics of each source, highlighting the importance of a the high energy coverage provided by INTEGRAL.

Lorenzo Natalucci

GRINTA, an explorer of the multi-messenger and transient sky

The Gamma-Ray International Transient Array observatory (GRINTA) has been conceived as a major breakthrough in the next decade (>2030) time domain astronomy, in particular for the multi-messenger domain. GRINTA, proposed to ESA as a 'fast' mission to be launched in the 2030/31 time frame, will provide access to the observation of EM emission from sources of gamma-ray bursts, gravitational waves and high energy neutrinos. These transient signals are known to occur in extreme environments and then produce hard X-rays that, in comparison to optical photons are not subject to high absorption and can be detected by an instrument with fast repointing capability and high sensitivity. The detection of high energy electromagnetic (EM) counterparts of gravitational waves, neutrinos and high energy gamma-ray sources is the main goal of GRINTA. The mission will also provide important survey science with its large field of view and high location accuracy (∼20'). The GRINTA S/C is proposed to fly in a nearly equatorial Low Earth Orbit. It will explore the transient hard-X/gamma-ray

sky implementing a ∼8 steradian FoV soft gamma-ray detector, paired to a highly sensitive hard X-ray imager. Its design and operational concept take full advantage of the heritage of the Swift and INTEGRAL missions in terms of rapid follow-up and survey capability.

Francesca Panessa

Multiwavelength variability of NGC 2110

The structure and energetics of the innermost regions of black holes are still matter of debate. In particular a lot of the attention is given to the understanding of the surrounding material close to the black hole, as well as to the connection of the inflowing and the outflowing material in disks, winds and jets. We have identified the Seyfert galaxy NGC 2110, one of the brightest AGN at hard X-rays, as an ideal laboratory to investigate both issues through its multi wavelength variability. On one hand, variable absorption has been measured in the past, in the form of partial covering material. On the other hand, NGC 2110 might represent a transition object between a radio quiet and a radio-loud galaxy. Variability has been observed at 8.4 GHz with the VLA (with decrease of ∼40% in flux over 7 years). Here we present the study of the variability properties of NGC 2110 at X-rays, hard X-rays and radio frequencies aimed at testing the connection between the X-ray and radio emission and looking for possible multi frequency time lags.

Alessandro Papitto

Low-mass X-ray binaries with INTEGRAL

Low-mass X-ray binaries (LMXBs) dominate the energy X-ray output of our Galaxy. They are ideal systems to study the details of accretion onto a compact object and phenomena occurring at the surface of neutron stars (e.g. pulsations, thermonuclear burning). During 20 years of INTEGRAL operations, the large field of view, good angular, spectral and temporal resolution of its instruments up to the hard X-ray/soft gamma-ray band ensured it a key role to measure the properties of LMXBs. I will review the main results obtained from LMXBs hosting a weakly magnetized neutron star. In particular, I will focus on the study of the spectral states and transitions up to hard X-rays and to the discovery and characterization of several accreting and transitional millisecond pulsars.

Elena Pian

AGNs: Future Perspectives and Synergies

AGN are bright hard X-ray sources and a primary target for INTEGRAL. I will review their multi-wavelength variability, with a particular focus on the brightest radio-loud sub-class of blazars, and their multi-messenger relevance, in view of recent campaigns. The future prospects for their study at high energies, also coordinated with high-energy neutrino detectors, will be outlined.

Andrey Semena

Surveys of the Galactic Bulge and disk

Mikhail Pavlinskiy ART-XC telescope on board of the SRG observatory was designed specifically to perform sky surveys in the hard X-ray band. Its observational mode allows it to cover uniformly large areas up to dozens sq.deg. and a stable background environment much facilitates the homogeneity of obtained surveys. The telescope working energy band 4–30 keV allows to mitigate much of the observational bias caused by the absorption. Given these advantages two deep surveys of central parts of our Galaxy were performed during the performance verification phase, that allowed us to detected about two hundred sources, including several dozens new ones. I will discuss the characteristics of these surveys and the content of the obtained catalogues of point sources. This work is supported by the Russian Science Foundation grant 19-12-00423.

Lara Sidoli

The Supergiant Fast X-ray Transients taken to new extremes

The Supergiant Fast X-ray Transients (SFXTs) are X-ray binaries showing a very variable X-ray flux. However, they reach also other kinds of extreme behaviors: we discuss here recent results about the least and the most absorbed SFXTs. IGR J08408−4503 is the least absorbed SFXT. A new XMM-Newton observation caught it in a faint state and thanks to the very low absorption towards the source, the X-ray spectrum could be deconvolved to three spectral components: two collisionally ionized plasmas plus a steep power-law model dominating above 2 keV. We interpreted the two-temperature plasma as the intrinsic X-ray stellar wind emission from the donor star (LM Vel), while the power-law as residual accretion onto the compact object. The emission contributed by the power-law component only ($5x10^{31}$ erg/s) is the lowest X-ray luminosity detected from the compact object in a SFXT. The candidate SFXT AX J1714.1−3912 is the most absorbed source. Its long-term X-ray emission shows a huge variability in its absorbing column density: here we report on the discovery of a very high obscuration (10^{24} cm^{-2}) serendipitously observed by XMM-Newton together with a 6.4 keV iron line. These properties make it one of the most absorbed sources in our Galaxy, resembling the so-called 'highly obscured sources' discovered by INTEGRAL.

Thomas Siegert

Diffuse Continuum Emission in the Milky Way

For more than 20 years, COMPTEL set the gold standard for measurements of the diffuse continuum emission in the MeV band. This most underexplored wavelength band holds information about high-energy processes whose details are often only vaguely or not at all determined: The Inverse Compton scattering of cosmic-ray electrons off the interstellar radiation field, the bremsstrahlung of electrons in ionised and neutral gas, the possible annihilation of positrons in flight, an unknown population of MeV point sources, or a signature of dark matter. In this talk, I will show that SPI finally superseded COMPTEL in measuring this diffuse emission component in the band between 1 and 8 MeV. Based on a careful data selection and a high-resolution model for the instrumental background, we were able to detect the diffuse MeV emission with more than 12σ. Standard cosmic-ray propagation scenarios underestimate the emission in this band, suggesting either that assumptions on cosmic-ray diffusion must be revised or that indeed an additional component in the MeV band is present.

Thomas Siegert

COSI — The Compton Spectrometer and Imager

For 20 years, the spectrometer SPI on INTEGRAL was and still is the only gamma-ray telescope to observe active nucleosynthesis in the Milky Way. The nuclear line emissions of the ^{26}Al decay from massive stars, ^{22}Na and ^{7}Be decay from novae, ^{44}Ti and ^{56}Co decay from supernovae, all have been studied with SPI. However, the distribution of positrons, which are the indirect proof of more beta-plus unstable isotopes in the Galaxy, follows an opposite trend: most of the annihilation radiation at 511 keV is found in the Milky Way bulge. This long-standing conundrum is difficult to solve with SPI as its sensitivity after 20 mission years will not improve significantly. In 2026, NASA's new gamma-ray mission COSI (Compton Spectrometer and Imager) will launch, mounting 16 high-purity Germanium strip detectors in a compact design. Compton imaging can improve the sensitivity at MeV energies by at least one order of magnitude, potentially revealing never-seen sources in the MeV sky, such as novae, 511 keV point sources, or individual Wolf-Rayet stars in ^{26}Al. Additionally, widely discussed events, such as pair plasma annihilation from microquasars in outburst, or polarization from transients (e.g. GRBs) and persistent sources, will be made possible with COSI. In this talk, I will give an overview of the need for a new instrument, introduce the new COSI mission using examples from its prototype's balloon campaign, and show the possibilities with the future COSI satellite mission.

Rashid Sunyaev

Recent High-Energy results

No abstract received.

Sergey Tsygankov

X-ray pulsars at low mass accretion rates

Historically, due to the limited sensitivity of existing instrumentation, broadband X-ray spectra of accreting X-ray pulsars (XRPs) have been studied at comparatively high luminosities, when most XRPs appear to have quite similar spectra with a characteristic cutoff power law continuum presumably associated with the comptonization of seed thermal or bremsstrahlung photons within the optically thick emission region. This only changed recently, when, thanks to the NuSTAR mission, we were able to detect a dramatic spectral transition in several transient XRPs. The typical cutoff power law continuum observed at high flux changed to a two-component spectrum peaking in soft ($<$10 keV) and hard ($>$20 keV) bands at low luminosity. On the other hand, observations of some others Be-transients revealed no such change at comparable luminosities. I will discuss these findings in context of the physical models of emission generation in the highly magnetized neutron stars. Finally, an insight into the physics of the low-level accretion onto the XRPs, gained from the first dedicated X-ray polarimeter, IXPE, will be considered in the framework of the same models.

Nikolai von Krusenstiern

From 'Why the IBIS on board Gamma Ray Burst Detector was removed in Phase-B' to today's operation at ESOC

A historic, opinionated view with a 'smile' on working for and with the Integral Mission ever since Phase-B in 1997 until today. Including, but not limited to some technical details of instrument and platform design & validation, operational events and team problem solving. This is based on the unique opportunity to have worked with and for Integral as an Astrophysicist, an Hardware-Engineer (HEPI: Hardware Event Pre-Processor for IBIS), Team Lead (IASW: IBIS On Board Software Development & Validation), Mission Specialist (Integral LEOP), and Operations as an Integral FCT: Flight Control Team member. [...]

Jörn Wilms

High-mass X-ray binaries future perspectives

Our understanding of high-mass x-ray binaries in the INTEGRAL era has enormously profited from the availability of broad-band observations in the soft and hard X-rays, the availability of all sky monitors, and the increased use of monitoring observations with pointed satellites. The next decade will bring further observational capabilities to the table, including polarization measurements (now available through IXPE) or high resolution spectroscopy that will become available with XRISM. The next step will be the big missions in the 2nd half of the 2020s and the 2030s, such as eXTP, Athena, or the NASA probe mission concepts. In this presentation I will try to give an overview of the main scientific questions in HMXB research that will be addressable with these new capabilities.

Robbie Webbe

Detection of Quasi-Periodic Eruptions in Extragalactic X-Ray Sources with Machine Learning

Quasi-periodic eruptions (QPEs) are a novel phenomenon in high-energy astrophysics, and to date have only been confirmed to be observed in four AGN. Characterised by high amplitude variability over relatively short timescales, QPEs have the potential to provide insights into the strong gravity regimes in the innermost regions of the accretion disks around AGN. To provide robust predictions of the physical mechanisms involved we need to find more QPE sources to broaden the understanding of the parameter space they inhabit. We use known observations of QPEs and simulated lightcurves to try and determine whether machine learning approaches can detect QPE sources, both in archival data and the large scale surveys expected in the near future.

Silvia Zane

Future Perspectives for neutron stars and magnetars in X-rays, gamma-rays

The ESA Integral satellite, launched in Oct 2002 and still operational, has revolutionised our understanding of compact objects, as neutron stars and magnetars, in the hard X-ray band. How to exploit this heritage and continue this kind of science in the next decades is now a challenge for the scientific community. In this talk I will briefly illustrate a few mission concepts, which are currently proposed to ESA, devoted to the study of hard x-ray and gamma ray transients. I will then discuss the current and future perspectives in the field of X-ray polarimetry and high resolution X-ray transients.

Shuang-Nan Zhang

Current and near-future space X-ray astronomy missions of China

In this talk I will briefly introduce several on-going and near-future space X-ray astronomy missions of China: 1) Insight-HXMT X-ray mission (launched on June 15th, 2017, mostly on X-ray binaries and GRBs); 2) GECAM (launched on December 10th of 2020, small satellites on GRBs and other transients from several keV to MeV); 3) SVOM (to be launched by the end of 2023, carrying optical and X-ray telescopes, a wide FoV hard X-ray imager and three gamma-ray monitors, mostly on GRBs and other transients); 4) EP (to be launched by the end of 2023, carrying many wide FoV lobster-eye X-ray telescopes and two narrow FoV X-ray follow-up telescopes, mostly on tidal disruption events, GRBs and many other transients); (5) CATCH (a proposed large constellation of small satellites carrying light-weight focusing X-ray telescopes, to follow and characterize many transients simultaneously, with the first path-finder satellites to be launched in 2023–2024); 6) POLAR-2 (the successor of POLAR operated on China's Tianggong-2 spacelab in 2016, to be placed onboard China's Space Station in 2024-2026, carrying GRB polarimeters covering several keV to several hundred keV energy range with spectroscopic and localization capabilities); 7) eXTP (a large X-ray observatory developed by a large Sino-European consortium for launch around 2027, carrying large arrays of X-ray timing, spectroscopy and polarimetry telescopes, as well as a wide field monitor); (8) HERD (a large cosmic-ray experiment developed by a Sino-European consortium onboard China's Space Station for operation around 2027, with unprecedented acceptance and energy range for direct measurements of cosmic-rays, electrons and gamma-rays in space).

Andreas Zoglauer

Enhancing the data-analysis pipelines of COSI and AMEGO-X with machine learning

The next generation of gamma-ray telescopes, such as COSI which is scheduled to launch in 2026 as well as the envisioned AMEGO-X and ASTROGAM missions, have a deep, multi-step calibration, reconstruction, and analysis pipeline. Many steps in this pipeline are either regression or classification tasks and thus are destined to benefit from the use of modern machine-learning approaches. This project aims to implement and compare different machine-learning algorithms for individual steps in the pipeline, identify the best method, and then develop a robust verification procedure which ensures that the machine-learning approach is unbiased, i.e., it performs as expected over the full range of its input and output parameters. In general, these machine-learning approaches are trained with as realistic as possible simulations of the detector system, and then tested with simulations and, in the case of COSI, with ground calibrations and astrophysical observations performed during COSI's 2016 balloon flight. The steps for which we have explored machine-learning approaches include strip pairing, i.e., determining the hit location in cross-strip detectors using a random forest and a MLP neural network; identifying and separating coincident events in the detectors originating either from strong bursts/flares or PET imaging or background using a MLP network; event classification, e.g., Compton vs. pair event for AMEGO-X/ASTROGAM using a 3D convolutional neural network; recoil-electron tracking, i.e, finding the start point, the start direction, and total energy of the recoil electron in the AMEGO-X tracker using a 3D convolutional neural network; identifying incomplete absorptions, i.e., gamma rays whose energy is not completely contained in the detector using a random forest and a dense, fully-connected neural network; estimating the energy loss of high-energy pair events in AMEGO using a mixed-input neural network; and finding the overall Compton interaction sequence in the detector using a naive Bayesian, a random forest, a graph neural network, and a dense, fully-connected neural network approach. In the presentation, we will give a brief overview of all the different approaches. However, the focus will be on Compton event reconstruction, where we will describe the design choices which allow us to reach peak performance, explain the challenges to deploy machine-learning

approaches to real astrophysical data, show the testing procedure which enables us to verify that the approach is unbiased, and finally compare the different approaches using COSI calibration measurements.

Poster Presentations

Listed alphabetically by presenting author last name

[Poster #1] Julia Alfonso-Garzón

20 years of INTEGRAL/OMC optical monitoring of high-energy sources

[Alfonso-Garzón, Albert Domingo, J. Miguel Mas-Hesse Centro de Astrobiología (CAB), CSIC-INTA, Madrid, Spain.] OMC, the Optical Monitoring Camera onboard INTEGRAL, has been monitoring the optical emission of hundreds of high-energy sources during the last 20 years. OMC performs optical V-Johnson observations with exposure times of 10, 50, and 200 seconds, simultaneously to the high-energy observations obtained by the other instruments on INTEGRAL (IBIS, SPI and JEM-X), downloading in addition the photometric data for around 100 objects within its 5°x5° field of view. In this contribution we review some representative results derived from the analysis of simultaneous optical and high-energy observations using OMC data, including AGN, X-ray binaries, cataclysmic variables, and even supernova explosions. At the end of the INTEGRAL mission, we will compile and publish the final INTEGRAL/OMC catalogue, containing the complete ready-to-use light curves and variability analysis of all the sources monitored by OMC during its lifetime.

[Poster #2] J. Michael Burgess

ApolloX: Exploring GRBs with Apollo 15

We present a 3ML plugin that allows for the study of Apollo 15 X-ray data. The plugin allows for localization and spectroscopy of the data. Preliminary results for a possible GRB and Sco X-1 are shown.

[Poster #2] Albert Domingo

20 years of INTEGRAL/OMC complementary science

[Albert Domingo, Julia Alfonso-Garzón, J. Miguel Mas-Hesse Centro de Astrobiología (CAB), CSIC-INTA, Madrid, Spain.] The Optical Monitoring Camera (OMC) has been observing the optical emission from the prime targets of the gamma-ray instruments on-board the INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL) since its launch on 17 October 2002. Simultaneously to these observations of the prime targets, OMC has been acquiring data from about 100 objects of interest within its 5°x5° field of view of each exposure, mainly optically variable or suspected variable sources. The analysis of these complementary observations has led to many interesting scientific results. After 20 years of INTEGRAL/OMC observations, the OMC Archive, publicly available at http://sdc.cab.inta-csic.es/omc/, contains the light curves of about 98000 scientific objects with more than at least 50 photometric points. Furthermore, in 2012 we published the first INTEGRAL/OMC catalogue of variable sources, where we provided a compilation of clean and ready-to-use OMC light curves of a selected sample, together with some useful information on the variability and periodicity of these sources. In this contribution we summarise the present contents of the OMC Archive and review some of the most interesting results on OMC complementary science using data from the OMC Archive and/or the first INTEGRAL/OMC catalogue, obtained by the scientific community so far for different types of variable sources.

[Poster #3] Mikhail Gornostaev

Continuum of an accretion column with a collisionless shock wave: analytical consideration

Analytical solutions are considered for a continuous spectrum of radiation formed in a two-dimensional region under a collisionless shock in accretion columns. The Comptonization parameter is determined in an efficient way and takes into account magnetic fields that reduce the average number of photon scatterings. The height of the shock wave above the surface of a neutron star is estimated depending on the relative change in the energy of the cyclotron line. The latter, as is known, can differ markedly from source to source, and therefore it can be considered as a parameter. The behavior of the X-ray rigidity of the continuum is studied as a function of the usual parameters of the problem for the cases of quasi-spherical and disk accretion. The influence of free-free processes is estimated (comments on the effective path length and effective thicknesses). Examples of estimating

the size of the radiating region for specific sources are given. Analysis of known solutions that take into account free-free processes.

[Poster #4] James Rodi

Exploring the Nature of the Hard X-ray/Soft Gamma-ray Emission of Cen A

Despite decades of observations, the nature of the hard X-ray/soft gamma-ray emission of Cen A, the brightest radio-loud AGN in the hard X-ray sky, is still unclear. The two main competing models are thermal Comptonization and synchrotron self-Compton emission. They predict a spectral cutoff of roughly 300 keV or >1 MeV, respectively, and require spectral coverage to the MeV region to differentiate. Using archival data and observations from the current INTEGRAL AO, we investigate Cen A's spectrum using both SPI and IBIS/ISGRI to better understand the soft gamma-ray emission and the process at work in that energy range. Also, we search for spectral variability in light of recent results from Swift/BAT.

[Poster #5] Stephane Schanne

The ECLAIRs/UGTS scientific trigger and data processing unit onboard the SVOM satellite: status and ground calibration results

The French-Chinese mission SVOM dedicated to Gamma-Ray Bust studies is currently undergoing its final development and test phases. The SVOM satellite is composed of 4 on-board instruments, observing the sky in gamma-rays, X-rays and visible-band. Among those the ECLAIRs coded-mask imager observes a large sky field in hard X-rays. The onboard Data Processing and Scientific Trigger Unit of ECLAIRs (UGTS) acquires and sends those data to the mass memory, and in parallel analyzes them in its trigger software, which performs coded-mask deconvolutions to produce sky images, to search for unknown transient point-like sources, for which it produces alert messages sent to ground-observers. For high significance alerts, it requests a spacecraft slew, to perform afterglow follow-up observations with the X-ray and visible-band telescopes. This paper presents the status of the UGTS flight software and the performances obtained during calibration campaigns in 2021, with the instrument operated in thermal-vacuum-chambers, using radioactive sources and an X-ray generator to simulate point-like sources. The UGTS mask deconvolution software was tested and first images obtained on ground with the complete ECLAIRs camera coupled to the UGTS.

[Poster #6] Philipp Thalhammer

Long-term spectral evolution of Cyg X-1 as seen through INTEGRAL

We present an overview of the long-term spectral evolution of Cyg X-1 over the last 19 years as seen by INTEGRAL. We analyzed the available IBIS/JEM-X & SPI data spanning 10–2000 keV. We identify state transitions and model the spectrum in the hard, soft, and intermediate state corresponding to different accretion disk configurations. This analysis includes an additional 2.2 Ms of exposure since the last comparable analysis has been performed, most of which in the soft state, allowing us to significantly improve on statistical uncertainties. Further, we show the evolution of spectral parameters through the years tracing changes in the source geometry.