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DIVISION XI SPACE & HIGH-ENERGY ASTROPHYSICS

ASTROPHYSIQUE SPATIALE & DES HAUTES ÉNERGIES

Division XI connects astronomers using space techniques or particle detectors for an extremely large range of investigations, from *in-situ* studies of bodies in the solar system to orbiting observatories studying the Universe in wavelengths ranging from radio waves to γ-rays, to underground detectors for cosmic neutrino radiation.

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TRIENNIAL REPORT 2006 - 2009

1. Introduction

Division XI was born by merging Commission 44 *Space and High-Energy Astrophysics* and Commission 48 *High Energy Astrophysics* by the decision at the IAU General Assembly in Den Haag (1994). While historically, space astrophysics started with the high-energy range only accessible form space, in modern astronomy almost all subfields are utilizing or planning to build space observatories. On the other hand, during the last few years, ground-based very-high-energy (TeV) γ-ray astronomy has emerged as a truly observational astrophysical discipline, and other ground-based facilities like gravitational wave antennas, neutrino detectors high-energy cosmic ray arrays stand by to join the era of multi-messenger astrophysics.

The IAU Division XI therefore has a quite broad range of scientific interests and observing methods, which is however naturally biased towards high-energy astrophysics. This situation is also reflected in the Division membership, which is quite large, but the majority of the members are high-energy astronomers. Other astronomy communities often choose their Division by astrophysical interest rather than wavelength. This difficulty, which is also existing in some of the other more wavelength oriented Divisions, has been addressed in the previous triennial report of Division XI (2003 - 2006) and is a matter of an active debate in the IAU Executive Committee, which hopefully will lead to some adjustments to the Division structure.

Scientifically, the Division XI is enjoying very exciting and prosperous years, many missions in a variety of fields are in orbit and being operated actively. Several new missions have been launched recently, others are in preparation and waiting for launches in the near future. The missions cover almost the whole range of wavelengths, from radio astronomy to gamma ray astronomy, as well as even facilities related to particle astrophysics and gravitational wave detections. Their productivity is enormous and it is beyond the scope of this report to cover them completely, so only a brief summary of major activities will be given with help of the board members.

2. X-ray and γ-ray astronomy

2.1. *Facilities in operation*

2.1.1. *Chandra*

Since its launch in July 1999, the *Chandra* X-ray Observatory has been NASA's flagship mission for X-ray astronomy. With its arcsecond angular resolution, *Chandra*'s capabilities have contributed to a wide variety of astronomical studies including mapping the distribution of heavy elements and obtaining evidence for the acceleration of cosmic rays in supernova remnants, detecting X-ray flares from Sgr A* and a large population of nearby stellar mass black holes, measuring the size and intensity variability of knots in the jets from AGN, determining the power and age of AGN outbursts by measuring the cavities created in the hot gas in galaxies and clusters of galaxies, using clusters of galaxies to constrain cosmological parameters including the equation of state for dark energy, providing strong evidence for the existence of dark matter through X-ray and lensing observations of the Bullet cluster which show the positional offset of the luminous material from the dark matter, and through very deep observations, resolving much of the extragalactic X-ray background and of the Galactic ridge emission into discrete sources. Recently, *Chandra* could identify the youngest supernova remnant in our Milky Way, which must have exploded only 140 years ago. GoogleSky now includes *Chandra* images.

2.1.2. *XMM-Newton*

With its three co-aligned X-ray telescopes providing large collecting area and good high energy response up to 12 keV, ESA's *XMM-Newton* excels in obtaining high throughput X-ray imaging, timing and spectroscopy for a wide range of astrophysical sources from comets and planets to quasars and clusters of galaxies. Recent notable accomplishments include constraints on the spin as well as the mass of black holes in Active Galactic Nuclei, the discovery of quasi-periodic oscillations (QPOs) in several ULXs, the demonstration that cool gas is being uplifted by bubbles from the Virgo cluster core, and the release of the second XMM Serendipitous Source Catalog, or 2XMM, which contains 192,000 unique sources drawn from 3491 *XMM-Newton*-EPIC observations and covers a sky area of 330 square degrees. It is the largest X-ray source catalog ever produced. One of the recent highlights from the mission is the analysis of the slew observations, when the satellite moves from one target to another. This way a nova explosion could be identified recently, which although in principle visible to the naked eye, was missed by all optical observations. In a similar fashion, *XMM-Newton* could identify new candidates for for tidal disruption events from stars swallowed by black holes in the center of normal galaxies.

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2.1.3. *SUZAKU*

The 5th Japanese X-ray astronomy satellite *SUZAKU* (*Astro-E2*) was launched in July 2005. With its excellent CCD energy-resolution in the soft X-ray range, its comparatively low intrinsic background, and its unprecedented sensitivity in the hard X-ray band, *SUZAKU* now works as a powerful wideband X-ray observatory yielding exciting results. Science highlights concern imaging spectroscopy of hot plasmas in SNRs, our Galactic center, and clusters of galaxies, revealing the distribution of density, temperature, and abundance, as well as broad Fe-K lines from black holes and neutron stars which reveal strong gravitational effects and black hole spins. *SUZAKU* broadband observations of AGN detected in the *Swift*-BAT hard X-ray survey indicate a new class of as yet unrecognized, heavily absorbed Seyfert galaxies. One of the recent highlights, e.g., concerns the discovery of solar-wind charge-exchange X-ray emission from the Earth's magnetosheath, which can have fundamental consequences for the interpretation of the soft X-ray background.

2.1.4. *RXTE*

The *Rossi X-Ray Timing Explorer* (*RXTE*) celebrated its 12th launch anniversary in 2007 and continues to make important scientific discoveries. *RXTE* observations have been crucial to the study of millisecond timing properties of accreting neutron stars as well as finding fast spinning neutron stars in low mass X-ray binaries, some of which may be intermittent pulsars. *RXTE*'s throughput and fast timing have enabled new results on the micro-quasar GRS 1915+105 that argue for a maximally spinning black hole. The QPO in XTE J1650−500 led to determine the currently smallest black hole mass of only 3.8 ± 0.5 $M_{\odot}$. *RXTE* observations of 4U 1636−53 directly showed the separation between unstable and marginally stable nuclear burning, as the QPO frequency drifted down to about 8 mHz and ceased, when a burst occurred. Another major accomplishment has been the demonstration that Anomalous X-ray Pulsars and Soft Gamma-ray Repeaters are magnetars, neutron stars with very strong magnetic fields. *RXTE*'s long lifetime has allowed recurrent transients such as the black hole system GX 339−4 to be studied during successive outbursts. Another recent highlight was the analysis of the Galactic ridge X-ray emission constructed from the 3-20 keV *RXTE* scan and slew observations. This emission follows closely the Galactic stellar mass distribution. These observations ended a decade long debate about the nature of the ridge emission, which is now interpreted as the sum of weak X-ray sources, mostly cataclysmic variables and coronal active binaries.

2.1.5. *Swift and HETE-2*

After the successful launch and operation of *HETE-2*, which provides γ-ray burst triggers on a regular basis, the field has been transformed by the launch of the *Swift* γ-ray burst mission. Since its launch in November 2004, *Swift* has detected more than 300 Gamma-ray bursts (GRBs), including nearly 30 short GRBs. A recent highlight was the discovery and identification of an exceptionally luminous burst at a redshift $z = 6.3$, comparable to the most distant galaxies and QSOs. The burst detected on 19 March 2008 made headlines as the first 'naked eye' GRB when the optical emission from this redshift $z = 0.937$ source reached 5.5 mag. In the burst GRB 060729, *Swift* observed the power-law decay of the X-ray afterglow for more than 100 d following the burst, suggesting that the jet may have a large opening angle. *Swift* also observed the actual supernova explosion of a giant star in January 2008, which was followed-up with extensive multi-wavelength observations. An ongoing *Swift*-BAT survey has detected 250 active galactic nuclei, with about 10-20% of them being heavily obscured by dust. Also in non-GRB observations,

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in April 2008, *Swift* detected a giant flare from the young star EV Lacertae that was thousands of times more powerful than any observed from our middle-aged Sun.

2.1.6. *INTEGRAL*

The *INTErnational Gamma-Ray Astrophysics Laboratory* (*INTEGRAL*), an ESA mission in cooperation with Russia and the United States, was launched in October 2002 to study gamma-ray sources in the energy range 15-10 MeV. A recent highlight is the discovery of a significant asymmetry of the spatial distribution of the 511 keV annihilation emission line in the Galactic disk, which resembles an asymmetry in the distribution of hard low mass X-ray binaries and possibly eliminates the need for more exotic explanations, such as those involving dark matter. *INTEGRAL* observations of Al^{26} at 1.8 MeV detect the signature of Doppler shifted emission caused by the rotation of the Milky Way. *INTEGRAL* observations have also discovered a population of obscured high-mass X-ray binaries with OB supergiants as the companion stars. Recently a long *INTEGRAL* observation of the binary pulsating X-ray source Her X-1 showed a significant increase in its spin that was several times greater than the average spin-up rate. The third *INTEGRAL* catalog lists 421 sources mostly identified with black hole or neutron star binaries or with active galaxies, but with 25% of the sources still unidentified.

2.1.7. *AGILE and GLAST*

Two new high-energy (GeV) γ-ray missions have been launched recently. *AGILE*, a small Italian satellite, was launched in April 2007 into an equatorial orbit with a very low particle background and is providing first scientific results. The *Gamma-ray Large Area Space Telescope* (*GLAST*) is an international and multi-agency mission designed to observe objects from 10 keV to 300 GeV. *GLAST* carries a Large Area Telescope (LAT), as well as a Gamma Burst Monitor (GBM). *GLAST* was successfully launched on 11 June 2008. Although just completing its two month check-out period, it has already observed a dozen γ-ray bursts and detected the blazar PKS 1502+106. With its unprecedented sensitivity and angular resolution, the *GLAST*-LAT will transform our knowledge of the γ-ray sky.

2.1.8. *H.E.S.S. and MAGIC*

During the last years, very-high-energy (TeV) γ-ray astronomy has emerged as an observational discipline, largely driven by the European-led High-Energy Stereoscopic System (H.E.S.S.) and the Major Atmospheric Gamma-ray Imaging Cherenkov (MAGIC) telescope. More than 70 TeV γ-ray sources have been detected, representing different galactic and extragalactic source populations such as young shell type supernova remnants, pulsar wind nebulae, giant molecular clouds, Wolf-Rayet stars, binary pulsars, micro-quasars, the Galactic Center, Active Galactic Nuclei, and large number of yet unidentified Galactic objects. Of particular cosmological importance is the upper limit on the extragalactic IR background light provided by the TeV observations of nearby AGN.

2.2. *Missions in preparation*

2.2.1. *Astrosat*

India's first Astronomy Satellite, *Astrosat*, is getting ready for launch by ISRO in late 2009. A general purpose multi-wavelength satellite, it will cover the X-ray spectral band from 0.3 to 150 keV with three co-aligned X-ray instruments, and provide simultaneous UV and optical coverage with two 40 cm telescopes. A Scanning Survey Monitor will look for transient X-ray sources in the sky.The three X-ray instruments are (*i*) Large Area high pressure Xenon Proportional Counters (LAXPC) with a total area of 6000 cm^2; (*ii*) a Soft X-ray focusing Telescope (SXT) of 2 m focal length using conical foil mirrors with gold surface and a CCD detector; and (*iii*) a CdZnTe Imager (CZTI) having a coded aperture mask.

2.2.2. *NUStar*

The *Nuclear Spectroscopic Telescope Array* (*NuSTAR*) is a NASA SMEX mission with a launch foreseen in 2011 that will open the high-energy X-ray sky for sensitive imaging studies for the first time. By focusing X-rays at energies up to ∼ 80 keV, *NuSTAR* will answer fundamental questions, e.g., about black holes and the formation of the elements.

2.2.3. *Spektr-Röntgen-Gamma (SRG)*

The Russian *Spektrum-Röntgen-Gamma* (*SRG*) platform is planned for a launch in 2011. It will perform a new sensitive X-ray all-sky survey in the energy band up to 12 keV. One of the main goals of the eROSITA telescope aboard *SRG* is to study Dark Energy through X-ray observations of ∼ 100 000 clusters of galaxies.

2.2.4. *Astro-H (NeXT)*

The X-ray observatory mission NeXT was approved by JAXA for a launch in 2013 and was named *Astro-H*. The two major new capabilities of this observatory will be high-resolution spectroscopy of $E/dE > 1000$ at 6 keV and hard X-ray imaging up to 60 keV.

2.2.5. *SVOM*

The *Space multi-band Variable Object Monitor* (*SVOM*) is a mission prepared in a Chinese/French collaboration aimed at continuing the investigation of γ-ray bursts. The launch is scheduled for 2013.

2.2.6. *The International X-ray Observatory (IXO)*

In May 2008 ESA and NASA established a coordination group involving ESA, NASA and JAXA, with the intent of exploring a joint mission merging the ongoing *XEUS* and *Constellation-X* into developing an *International X-ray Observatory* (*IXO*). The starting configuration for the *IXO* study will be a mission featuring a single large X-ray mirror and an extendable optical bench with a 20-25 m focal length, with several instruments on an interchangeable focal plane. This plan establishes an *IXO* study, which will be the input to the US decadal process and to the ESA selection for the Cosmic Vision Plan. The *IXO* study supersedes the ongoing *XEUS* and *Constellation-X* activities.

3. UV, Optical, infrared/submillimeter and radio astronomy

3.1. *Missions in operation*

3.1.1. *GALEX*

The UV mission *GALEX* (*Galaxy Evolution Explorer*), a successor of *FUSE*, is making extensive surveys of galaxies with its wide field of view UV cameras. With its capabilities complementary to *HST*, the global structure of star formation activity in the galaxies is well contrasting the general stellar population.

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3.1.2. *HST*

In August 2008, in its 18th year of operation, NASA's *Hubble Space Telescope* has celebrated its 100 000th orbit with a spectacular image of a star forming region near the star cluster NGC 2074. By a continuous restoration and addition of new instruments, *HST* keeps a leading role at the forefront of astronomical discoveries. The Advanced Camera for Surveys (ACS), installed in 2002, provided a major breakthrough in imaging capability and was at the heart of many new scientific results. It, e.g., helped to pinpoint a likely intermediate mass black hole in the core of the spectacular globular cluster ω Centauri. The camera was used to image the GOODS North and South fields, as well as the COSMOS field to unprecedented depth and solid angle. It was also used to discover and study more than 20 new distant Type Ia supernovae and thus to trace the history of cosmic expansion over the last 10 billion yr. Unfortunately, ACS failed in 2007, but NASA decided to pursue the fourth *Hubble* Servicing Mission (SM4), which is planned in October 2008 and will bring new instruments to the telescope. In addition to the Wide Field Camera-3 (WFC3), the Cosmic Origins Spectrograph (COS) will be inserted. It will also aim to repair the Space Telescope Imaging Spectrograph (STIS) as well as ACS. New batteries and gyros will maintain the telescope's power and pointing systems and should hopefully extend *Hubble*'s lifetime to at least 2013, by which time NASA will be getting close to launching *JWST*.

3.1.3. *Spitzer Space Telescope (SST)*

Following the great success of *ISO*, the *Spitzer Space Telescope* was launched in 2003 into an Earth-trailing solar orbit, and is expected to continue operating at cryogenic temperatures until spring 2009. The combination of low background and new detector technology have enabled superb sensitivity and mapping speed. The spectroscopic coverage of *Spitzer* (5-38 μm) has encompassed phenomena ranging from planets orbiting other stars to galaxies at $z \simeq 3$, a mere 2 Gyr from the Big Bang, while *Spitzer* deep imaging (3.6, 4.5, 5.8, 8.0, 24, 70 and 160 μm) has reached the most distant objects known to date, galaxies at $z \simeq 7$. This has made *Spitzer* an essential element in the fabric of international astronomical research. More than 2 700 individuals from over 24 countries have become active *Spitzer* PIs or co-Is, and more than 1 100 refereed papers have been published based on 4.25 years of *Spitzer* operation.

Among its many discoveries and results, *Spitzer* demonstrated that mature galaxies exist at redshifts $z > 6$, i.e., less than 1 Gyr after the Big Bang. Some of these galaxies may be sufficiently massive to challenge the accepted theoretical framework of galaxy formation. It resolved the infrared background into discrete sources, galaxies and obscured AGN, and enabled a census of these objects during the peak of star and galaxy formation activity at redshifts $1 < z < 2$. *Spitzer* generated arcsecond-resolution maps of more than 200 deg^2 of the Milky Way, equivalent to a full accounting of all star formation in our Galaxy. It revealed the signature of dust formation in the Cas A supernova remnant. *Spitzer* data have led to an understanding of the building of planetesimals in the circumstellar disks of young stellar objects. It has shown that comets have a mineralogy similar to that of dust debris disks surrounding nearby stars. *Spitzer* went beyond the first direct detection of exoplanets, and has collected data to characterize their physical properties such as density and gas/rock structure and their surface temperature distribution. It has offered the first detection of water vapor absorption in an exoplanet atmosphere. After *Spitzer* runs out of its Helium cryogen, it is expected to continue operating in the two shortest bands at 3.6 and 4.5 μm with essentially the same sensitivity; this phase of warm operations with the focal plane between 25 and 30 K might last several years. This mode of operation will be open to the international astronomical community with the same peer-review philosophy followed until now.

3.1.4. *AKARI (ASTRO-F) and SPICA*

The first Japanese infrared satellite *AKARI* launched in February 2006, has been operated very successfully. It completed its all sky survey by August 2007, covering 94% of the whole sky with better sensitivity and angular resolution than *IRAS*, in the whole infrared region. The northern and southern ecliptic polar regions have been extensively mapped, providing extremely deep surveys, including the Lockman Hole and LMC areas. Besides the general survey, about 5 000 pointing observations have been made for individual sources, covering planetary sources, young and old stars, galaxies and ULIRGs. The capability of near infrared grism spectroscopy is particularly valuable to observe spectra of brown dwarfs and AGNs. *AKARI* is still continuing its post helium phase in the near infrared range. The bright source catalogue will be released late in 2008 for the team members and to the public one year later.

Following the success of the *AKARI*, a more advanced infrared mission *SPICA*, a cryogenically cooled 3.5 m telescope for mid- and far-infrared observations is under planning in ISAS/JAXA. The implementation of the mission is under development in collaboration with ESA, aiming at a launch in 2017. Collaboration with the US and Korean communities is also in discussion.

3.1.5. *Wilkinson Microwave Anisotropy Probe (WMAP)*

The first major cosmology mission *COBE* took a great step towards establishing the Big Bang cosmology, with the perfect confirmation of the black body nature of the cosmic microwave background radiation and the first evidence of anisotropy in its brightness distribution. These pioneering milestones were awarded the Nobel Prize in 2007. The advanced mission *WMAP*, launched in 2001, has confirmed *COBE*s results perfectly with higher sensitivity and angular resolution. A simple cosmological model with only six parameters fits not only the *WMAP* temperature and polarization data, but also small-scale CMB data, light element abundances, large-scale structure observations, and the supernova luminosity/distance relationship. Therefore, *WMAP* and the other precision cosmology measurements have provided us with a highly accurate reference frame for further astrophysical studies of the early Universe.

3.2. *Facilities in preparation*

3.2.1. *TAUVEX*

The Israeli TAUVEX three-telescope array for wide-field imaging in the ultraviolet has been adapted for a mission on-board the geo-synchronous technological demonstrator satellite GSAT-4 of the Indian Space Research Organization. The Flight Model was undertaking the final calibrations in summer 2008, prior to shipping to Bangalore to be integrated with the satellite. The launch is planned for 2008/2009 for a >3 yr mission.

3.2.2. *Herschel*

Herschel is an ESA Corner-Stone Mission with instrument contributions by NASA, expected for launch in early 2009 into an L2 orbit, on the same rocket carrying *Planck*. It will be the first versatile far-infrared and submillimeter observatory, and the largest IR-capable telescope ever flown into space. Herschel offers imaging and spectroscopy from 55 to 672 μm on a passively cooled 3.5 m telescope equipped with three instruments (HIFI, PACS and SPIRE). *Herschel* will build on *Spitzer* results, pursuing unsolved questions with

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higher spatial resolution, and with spectroscopy at longer wavelengths, including very high spectral resolution with the heterodyne instrument HIFI. *Herschel* is well equipped to advance our understanding of interstellar chemistry and kinematics, critical processes in star and planet formation, and the structure and nature of powerful extragalactic sources known as Ultra-Luminous InfraRed Galaxies (ULIRG).

3.2.3. *Planck*

The *Planck Surveyor* (*Planck*), an ESA mission with NASA contributions, is an all-sky survey covering with nine bands the range from 350 μm to 1 cm. Expected to launch in early 2009 and to operate for at least 15 months, it is aimed at improving dramatically our measurement of the intensity and polarization of the Cosmic Microwave Background (CMB) and of astrophysical foregrounds at a resolution down to a few arcminutes. *Planck*s longest wavelengths overlap *WMAP*, and the shortest wavelengths extend far into the submillimeter in order to improve the separation between galactic foregrounds and the CMB. *Planck* will yield exquisitely sensitive maps of the Milky Way at wavelengths (1.4, 2.1, 3.0, 4.3, 6.8, & 10.0 mm and 350, 550 and 850 μm) and polarization maps at a few arcminute resolution in some of these bands and open up new vistas of research in Milky Way emission mechanisms, ISM structure, dust properties, and star formation processes. These data will be even more valuable when combined with the complementary maps produced by *IRAS*, 2MASS and *AKARI*, and those expected from *WISE*.

3.2.4. *SOFIA*

The atmospheric window for infrared observations opens up substantially at stratospheric altitudes, even though background emission remains a limiting factor. The *Stratospheric Observatory for Far-Infrared Astronomy* (*SOFIA*) is designed to exploit this opening by flying a 2.5 m telescope on board a modified Boeing 747SP airplane; it is a joint venture of NASA and DLR, the German Aerospace Agency. Besides the large aperture, the most exciting prospects of *SOFIA* derive from the concept of an ever-evolving instrument complement, with continual technology updates, allowing for breakthroughs on *SOFIA* and a path to space adaptation. *SOFIA* has flown many hours with the telescope cavity door closed, and is expected to observe first light while airborne in 2009.

3.2.5. *WISE*

The *Wide-field Infrared Survey Explorer* (*WISE*) is a NASA MIDEX mission expected to launch in late 2009, and map the sky at 3.3, 4.7, 12 and 23 μm to a sensitivity ranging from 0.1 to a few mJy. With its cooled 40 cm telescope, it is expected to detect a hundred million objects, including the most luminous galaxies and quasars in the Universe. *WISE* will be able to complete the nearby census of stars and brown dwarfs down to extremely low temperatures within several tens of parsecs of the Sun.

3.2.6. *Astro-G (VSOP-2)*

The space radio VLBI mission *VSOP-2* has been approved by JAXA and is now named *Astro-G*. It is planned for launch in 2012. One of the major scientific aims is to resolve supermassive black hole shadows by very long baseline radio interferometry with ground based radio telescopes. It will achieve an angular resolution of 40 μm-arcsec.

3.2.7. *JWST*

The introduction of adaptive optics and interferometric technique has made ground based telescopes competitive to *HST* in resolution, particularly in infrared observations.

However, the superiority of the observational conditions in space, in particular regarding the infrared sky background and atmospheric transmission is irreplaceable. This is the motivation of implementing the 6.5 m *James Webb Space Telescope* (*JWST*), which is now under development and to be launched in 2013.

4. Other missions

4.1. *Gravitational waves. LISA*

Complementary to the operating ground-based gravitational wave detectors, as TAMA-300, GEO-600, Virgo and LIGO, a space mission, the *Laser Interferometer Space Antenna* (*LISA*) is under planning both in ESA and NASA. It is a long baseline laser interferometer for detection of gravitational waves, to be launched into an L2 orbit and a candidate for the ESA Cosmic Vision L1 slot.

4.2. *Ultra high-energy cosmic rays. Auger*

Cosmic rays of ultra-high energy remain one of the least understood phenomena in the Universe. A new international facility, the Pierre Auger observatory, a huge 3000 km^2 particle array combined with four wide-angle optical telescopes of atmospheric fluorescence light, located in Argentina, is now delivering its first, highly tantalizing results. These results demonstrate the existence of a statistically significant spectral feature (steepening or cutoff) at around 5×10^{19} eV. Also, a possible correlation between the arrival directions of the highest-energy cosmic rays, $\geqslant 6 \times 10^{19}$ eV, and the positions of nearby AGN has been reported. A Space Station borne mission called *JEM-EUSO* has been proposed as an international collaborative endeavor under Japanese leadership.

5. Summary

Space missions have been expanded to almost every field of astronomy and relevant to every kind of astronomical objects or phenomena. Dozens of missions are now in orbit and another dozen of missions are under development, awaiting launch in the coming years. The golden age of space observations will continue and the advanced missions will provide great strides of progress, in a variety of fields of astronomy. Many of the missions are carried out by large consortia, with multi-discipline participants. Sometimes, collaborations are organized among multiple missions and with groundbased observatories. Many missions are international in hardware developments and data analysis. As the scale of missions becomes larger, international collaboration is indispensable to afford the high cost and work force needed.

These developments should increase the importance of the activity of Division XI, but, at the same time, raise the complexity of its activities.

Günther Hasinger
president of the Division