

DIVISION XI

SPACE AND HIGH-ENERGY ASTROPHYSICS

*ASTROPHYSIQUE SPATIALE & DES HAUTES
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DIVISION XI COMMISSIONS

Commission 44

Space & High Energy Astrophysics

DIVISION XI WORKING GROUPS

Division XI WG

Particle Astrophysics

INTER-DIVISION WORKING GROUPS

Divisions IX-X-XI WG Astronomy from the Moon

Division XI is organized by astronomers and astrophysicists who are mainly involved in space astronomy and their relevant research fields. Thus the Division XI members represent a very broad community, including radio, infrared, optical, ultraviolet, X-ray, and gamma ray, as well as cosmic ray observers and theorists. The topics of interest to the Division were extended to the study neutrino, astrophysical particles and gravitational waves, but these are currently under-represented in the Divisional membership. The relevant investigations cover almost all astronomical topics from our Solar System, stellar, Galactic and extragalactic research to studies of the deep space Universe and cosmology. This implies that communication and cooperation among the Division members, and cross-fertilization with members of other Divisions, are important and helpful to promote new space and ground based observatories and to enhance their scientific value.

TRIENNIAL REPORT 2009-2011

1. Organizational issues

Originally, Division XI concerned itself only with high-energy astrophysics (in particular UV, X-ray and gamma rays), to which was later added the domain of lower-energy astrophysics where observations are generally performed from space (optical, infrared, submillimeter and parts of the radio spectrum). The Division also includes ground-based high energy gamma ray and cosmic ray experiments, gravitational wave, and Moon-based

astronomical observations. The individual expertise of the present OC reflects primarily the UV and higher energy domains. However, since there are plans within the IAU to restructure divisions, we propose that, following the changes in the Divisional structure and renewal of the OC, the new members will be recruited to broaden the spectral range of research covered by the Division.

Division XI subsumes now a single Commission (#44, having the same name as the Division and the same OC as the Division) and two Working Groups (“Astronomy from the Moon”, which is an inter-divisional WG together with Divisions IX and X, and “Particle Astrophysics”). While the Astronomy from the Moon WGs is active, the Particle Astrophysics WG should be substantially changed under the new IAU structure. We propose to restructure the Particle Astrophysics WG, rename it “Astroparticle WG” and invigorate it by inviting new members from the high energy physics community to join the IAU and this working group.

In the proposed restructuring of the Divisional structure of the IAU, some areas of fundamental physics, including astroparticle physics, would come under the new division that would succeed the present Division XI. We propose to initiate a strong recruiting effort among high-energy physicists to join the new Division and initiate more cross-fertilization between particle physics and astrophysics within the IAU. With this change, since the IAU Commissions will be retained after the IAU restructuring effort, it may be beneficial to create a number of new Commissions within the new Division to deal with, e.g., Space Astronomy (including Astronomy from the Moon), High-Energy Astrophysics (both from space and from the ground), gravitational wave astrophysics, and Non-Photon (particle) Astrophysics. However, these possibilities must wait for the final restructuring decisions at the 2012 GA.

The Division now has a total membership slightly over 1000, which does not reflect the potential of interested Union members whose research includes using space-based instrumentation, or which touches the high-energy physics domain. Obviously, more efforts on the part of the OC to broaden the Division membership are in order.

2. Research developments within the past triennium

In this section we list active and planned space missions, separating them by wavelength (energy). We list first missions dedicated to the observation of deep space, excluding Solar System targets. These are the topic of § 2.2. When discussing different missions, we also include those approved or planned, but not yet launched, to provide a perspective on what is likely to be available in the future. The situation projected from the mission listing by wavelength range indicates a future deficiency in the UV domain, with no major facility available following the eventual termination of the HST mission.

2.1. Deep space research

2.1.1. X and γ -ray

The scientific activities pertaining to the Division’s scope of interest include the continuing observational activity of GALEX, Swift, AGILE, CHANDRA, SUZAKU, XMM-Newton, RXTE, INTEGRAL and FERMI at the energy range higher than that of the optical, HST in the UV-optical-near IR domain, Spitzer, WISE (operations terminated in February 2011), and Herschel in the IR, and ACE in the astroparticle field.

Since its launch in 1995, RXTE (the Rossi X-ray Timing Explorer Mission) has allowed the detailed study of X-ray variability on timescales from microseconds to months in the energy range from 2 to 250 keV for compact objects, most notably galactic black holes and neutron stars. LOFT (the Large Observatory for X-ray Timing) is one of four candidate

ESA M class missions now undergoing assessment and if selected for flight, LOFT will provide a very significant extension of the science capabilities of RXTE.

After 12 successful years in space, CHANDRA is still going strong, as demonstrated by the strong response to the 13th call for observing time. The 659 proposals oversubscribed the available observing time by a factor of 5.4. As one example of recent science results, measurement of the growth of structure through Chandra observations of nearby and distant clusters, confirmed the existence of dark energy, originally discovered through optical observations of distant supernovae.

XMM-NEWTON also is completing its twelfth successful year and continues normal operations. Among its accomplishments are the serendipitous detections of X-ray luminous galaxy clusters to $z \sim 1.6$. XMM has significantly increased the number of discovered distant systems in the first half of cosmic time ($z \geq 0.8$) to more than three dozen, which allow now a systematic look at the earliest formation history of the most massive objects in the Universe. Deep X-ray and optical observations of the COSMOS field showed that most AGN are not triggered by galaxy mergers.

Since its launch in 2004, SWIFT has discovered more than 600 Gamma-ray bursts. Their luminous afterglows can be detected at the highest redshifts. Of note is GRB090429B, whose photometric redshift is 9.4. Swift's fast scheduling ability and multiwavelength capability have allowed rapid X-ray and optical follow-up of new supernovae, variable stars, and AGN outbursts. Swift also has detected more than 1000 hard X-ray sources with its BAT instrument, most of which are AGN. Combining observations from different missions often leads to exciting results, such as the recent Swift, Chandra and XMM observations that show evidence for a cooling neutron star crust in the binary EXO 0748-676.

SUZAKU, Japan's fifth X-ray astronomy mission, was launched in 2005. Although the X-ray Spectrometer (calorimeter) lost its cryogen shortly after launch, the X-ray Imaging Spectrometer and Hard X-ray Detector continue to provide new observations. Recent scientific results include the detection of possible clumping in the baryons in the outskirts of the Perseus cluster. Suzaku, along with Astro-H, the sixth Japanese X-ray mission which is scheduled for launch in 2014, also can measure spins and study the hard X-ray emission from black holes in our Galaxy.

The Spectrum-X-Gamma (SXG) mission is currently under construction as a Russian-German X-ray astrophysical observatory. SXG will carry two powerful telescopes with imaging instruments, the eROSITA (extended ROentgen Survey with an Imaging Telescope Array) and ART-XC. Launch into an L2 orbit will be in late 2013. The first four years of the mission will be devoted to surveys of the entire sky, while the next 3.5 years will be used for pointed observations. eROSITA and ART-XC will perform deep surveys of the entire sky. eROSITA's sensitivity will be more more than thirty times that of ROSAT in the 0.5-2 keV band. Its best imaging, on-axis, will be 15", while the average blurring in the survey will be 28". ART-XC energy band (6 to 30 keV) will provide the first high energy map of the full sky. Due to the scan pattern, the highest sensitivities will be at the ecliptic poles.

eROSITA's sensitivity will result in a wealth of X-ray information on newly discovered clusters of galaxies, groups, galaxies, AGN, stars and compact objects. All massive clusters of galaxies in the Universe will be detected in the all-sky survey. Approximately 1100 clusters will be at $z \geq 1$. Measurements of the approximately 100,000 clusters will determine the growth of clusters over cosmic time and be used to place tight constraints on cosmological parameters, including σ_8 and the Dark Energy equation of state. In addition, tens of thousands of groups within 1 Gpc will be detected and used to trace large-scale filaments and to determine the outburst frequency and power of supermassive black holes. Three million AGN will be discovered, allowing a full census of radio and

Seyfert galaxies, quasars and blazars. In addition the X-ray emission from several 10^6 stars, including stellar flares, will be detected and quantified. Finally these observations will form the basis for the most complete X-ray luminosity function for Galactic X-ray sources. These very large samples of clusters, AGN, stars and galactic sources will allow the most interesting and rare objects to be discovered.

The hard X-ray sensitivity of ART-XC telescope and instrument will lead to the detection of several thousand AGN, including the heavily absorbed Compton-thick AGN. The ART-XC also will allow detailed studies of Galactic sources up to 30 keV and images of bright clusters, including the detection of merger shocks.

INTEGRAL, which was launched in 2002 is now in its extended science operations phase, was oversubscribed by a factor of 2.9 during the last allocation (AO-9). Its ability to carry out spectroscopy from 15 keV to 10 MeV, along with simultaneous X-ray and optical monitoring has led to many new results including a greater understanding of compact objects, from neutron stars to supermassive black holes, including the recent discovery from combined INTEGRAL, Chandra, XMM-Newton, HST and Swift observations of giant “bullets” of gas from the MKN509 black hole.

The Italian AGILE gamma-ray mission was launched in 2007 to survey the sky in the 30 MeV to 50 GeV band and the 18 to 60 keV hard X-ray band. In addition to imaging, AGILE provides sub-millisecond timing for the study of transient phenomena. Important scientific results include the discovery of variability in the Crab’s intensity (also see FERMI results) and the detection of gamma-ray emission from Cygnus X-3.

The FERMI Gamma-ray Space Telescope was launched in 2008 to observe the γ -ray sky from 30 MeV to 300 GeV (the LAT instrument maps with a field of view of about 20% of the sky) and from 150 keV to 30 MeV (the GBM instrument monitors the sky for γ -ray bursts). FERMI is operating nominally and, among its many scientific results, reported that the Crab Nebula is not a stable X-ray and gamma-ray reference source, showing intense flares and month-scale variations at hard X-ray energies (also see AGILE results). Another major breakthrough from Fermi is the discovery of dozens of radio quiet neutron stars.

The Nuclear Array Spectrometer (NuSTAR) satellite will be the first focusing high energy X-ray mission, allowing a sensitive survey of the hard X-ray sky. The Pegasus launch is scheduled for February 3, 2012, to begin NuSTAR’s two-year mission. This mission will use a dense nested-foil concentrator with 133 shells to observe in the spectral region from 10 to 80 keV, providing a much higher effective area at these energies than either Chandra or XMM-Newton and reaching a sensitivity of $0.8 \mu\text{Crab}$ in 10^6 seconds for the 10-40 keV band. NuSTAR will have an imaging capability of $10''$ (FWHM; $50''$ half-power) for a field of view of $12'.5 \times 12'.5$, and a spectral resolution of 0.6 keV at 6 keV, going down to 1 keV at 60 keV.

We note also that the International X-ray Observatory (IXO) is under intense review and redefinition at ESA and NASA. Both are carrying out studies to determine future missions.

2.1.2. *Ultraviolet and optical*

During the past three years, The Galaxy Evolution Explorer (GALEX) has continued its mission to study the basic structures of the Universe. Launched in April 2003, it has now completed more than 8 years in-orbit and its original 29 month mission has been extended several times. A recent scientific highlight combines GALEX data with observations made by the Anglo-Australian telescope to help confirm that dark energy is driving the Universe apart at accelerating speeds (results from the WiggleZ Dark Energy Survey; Drinkwater *et al.* 2010). The GALEX mission lost its FUV channel in

May 2009. Based on the 2010 NASA Senior Review Panel's recommendations, NASA announced that all GALEX observations will terminate at the end of September 2012. A final data release is planned. Given the mission status and future possible missions under consideration when this report was written, it is not likely that the GALEX capabilities will be significantly expanded within the next decade.

With the end of the FUSE mission on October 2007 and the failure of the electronics of the Space Telescope Imaging Spectrograph (STIS) on HST in August 2004, the availability of spectroscopic observations in the UV has been limited to the low resolution GRISM spectroscopy on GALEX, together with UV monitor telescopes on Swift and XMM-Newton. Therefore, the final HST servicing mission in May 2009 was of particular importance to UV astronomy. Apart from general health servicing of the spacecraft (batteries, gyros etc.), the plan involved the installation of two new scientific instruments, Wide Field Camera 3 and the Cosmic Origins Spectrograph (COS), and repairs to STIS and the Advanced Camera for Surveys. The mission was a tremendous success with all installation and repair goals achieved, making HST more capable than it has ever been.

India's first dedicated astronomy satellite ASTROSAT is planned for launch in April 2012. This mission will cover the spectral domain from hard X-rays to the UV. One of the instruments on board is the ultraviolet imaging telescope (UVIT) which consists of two Ritchey-Chrétien telescopes (37.5-cm diameter) providing simultaneous coverage of a 28' diameter field in three wavelength bands. One of the two telescopes is dedicated to the far-ultraviolet (FUV) channel with a wavelength coverage between 130 and 180 nm. The other telescope splits the incoming light into two channels using a dichroic mirror into an near ultraviolet (NUV) channel with a spectral coverage between 200 and 300 nm and a visible channel with coverage between 320 and 550 nm. The detectors are intensified CMOS detectors with an effective angular resolution of better than 2" in space. A number of broad and narrow band filters may be used to observe targets in different spectral bands while a transmission grating provides slitless spectroscopy in the FUV and NUV channels with a resolution of about 100.

Although most of the UVIT time will be in parallel with the X-ray telescopes to monitor the observed source, the UV team has a fraction of satellite time to observe their UV targets. Time for guest observers on ASTROSAT is planned following a PV phase, with a steadily increasing fraction for national and international proposals.

We note the effective termination of the TAUVEVX UV telescope by the Israel Space Agency following its removal from the Indian Space Research Organization GSAT-4 satellite (subsequently lost on launch in May 2010). We also note continued efforts in Russia during this triennium to prepare the World Space Observatory-UV (Spektr-UV) as a spectroscopic and imaging instrument for an eventual launch in 2013-2014.

The COROT satellite, studying transiting exoplanets and stellar astroseismology, has been operating normally in this period, and so has the MOST satellite of the Canadian Space Agency. The Kepler mission, with similar goals to these of MOST and COROT, but having significantly enhanced sensitivity, has been in operation since 2009 and has announced more than 1000 exoplanet candidates. Recently Kepler observations made the first unambiguous detection of a planet orbiting two stars (remember planet Tatooine from Star Wars?).

The GAIA (Global Astrometric Interferometer for Astrophysics) mission, to follow-up and enhance the Hipparcos mission, is being readied for a 2012-2013 launch on a Soyuz rocket. GAIA will operate at the L₂ point and is expected to produce a catalog of approximately 10⁹ stars to magnitude 20 with astrometry good to ~20 μas (microarcsecond) at 15 mag, and ~200 μas at 20 mag.

2.1.3. *Infrared and submillimeter*

The first Japanese infrared satellite AKARI launched in February 2006 and operated successfully, producing an \sim all-sky survey by August 2007. The mission continued despite the boil-off of its liquid Helium coolant, by using active cooling to only 40K and restricting the long-wave IR observations. The survey covered more than 96% of the entire sky with better sensitivity and angular resolution than IRAS in a wider wavelength range. The first point source catalog with 1.3×10^6 sources was released in March 2010. The all-sky images and the faint source catalogs will also be released in several years. Besides the all-sky survey, about 5,000 pointed observations had been made for selected sky areas and individual sources, including planetary sources, young and old stars, galaxies, and the cosmic IR background. More than 12,000 pointed observations were made in the near-infrared. The observations were terminated in May 2011, but the data reduction and archiving activities are continuing.

SPITZER, launched in 2003, has had very broad scientific impacts. For example, with Spitzer, astronomers have probed stellar nurseries in our Galaxy and also detected the red and dead galaxies in very high redshift clusters. Recently Spitzer images of Maffei 2 showed the structure of this nearby galaxy, which is almost completely hidden in visible light by dust clouds in our Milky Way. Spitzer has now run out of coolant and is operating in the “warm” Spitzer phase.

The Wide-Field Infrared Survey Explorer (WISE) mission was a NASA-funded Explorer mission carrying a 40-cm telescope and detectors cooled to 15K by solid hydrogen. It was launched in 2009 and ran out of cryogen on 29 September 2010. During this period WISE conducted a full survey of the sky in four IR bands: 3.1, 4.6, 12 and 22 μm . On 14 April 2011 a preliminary release of WISE data was made public, covering 57% of the sky observed by the spacecraft. The results of the full survey are scheduled to be released by March 2012.

SOFIA, (the Stratospheric Observatory for Infrared Astronomy) a modified Boeing 747 aircraft that carries a 2.5 meter telescope for observations in the mid-infrared to submillimeter range, began science flights in late 2010. SOFIA is a joint program by NASA and German Aerospace Center and is expected to have a 20 year lifetime.

The WMAP mission, which collected invaluable data on the cosmic microwave background for nine years at the L_2 location, was terminated on 28 October 2010. The combination of the WMAP and HST results yielded, for the first time, a Hubble constant good to a few %. Fortunately, the PLANCK satellite also at L_2 took over the CMB measurements from WMAP from July 2009, with enhanced sensitivity and angular resolution. Both the Early Release Compact Source Catalogue with thousands of sources detected by Planck and the Early Release Sunyaev-Zeldovich Catalogue of 189 clusters were released in January 2011.

Together with Planck, ESA launched the HERSCHEL spacecraft carrying the largest astronomical telescope ever launched with a 3.5 m-diameter primary mirror. The key science objectives of Herschel are to study the formation of stars and galaxies, and to investigate the relationship between the two, but other interesting results emerge continuously. For instance, a recent paper in *Nature* (Hartog *et al.* 2011) reported finding a very similar D/H ratio in outgassing from comet 103P/Hartley 2, strengthening the hypothesis that at least some H_2O on earth is of extraterrestrial origin.

The James Webb Space Telescope (JWST), planned to succeed HST and observe from L_2 in the 0.6 to 28 μm band with a 6.5-m telescope, is under review by the United States Congress after costing significantly more than originally proposed, and launching at least seven years later than planned.

ESA selected in 2011 the EUCLID mission to map the geometry of the dark Universe. The mission will investigate the distance-redshift relationship and the evolution of cosmic structures by measuring shapes and redshifts of galaxies and clusters of galaxies out to redshifts of ~ 2 . EUCLID is optimized for two primary cosmological probes: weak gravitational lensing and Baryonic Acoustic Oscillations (BAO). EUCLID will operate from the L_2 point and will use a modified Korsch telescope with a primary diameter of 1.2-m, and central obscuration 0.4-m. The visible channel will use a 600 Mpixel CCD mosaic that will image a field of view of 0.5 square degrees with $0''.2$ pixels. The near-IR channel will use a 7.5 Mpixel mosaic to provide photometry from 0.9 to 2.0 μm . EUCLID is now scheduled for a 2019 launch.

The Space Infrared Telescope for Cosmology and Astrophysics (SPICA) is a proposed Japanese-led mission with extensive international collaboration (ESA, Korea, etc.). SPICA is optimized for mid- and far-infrared astronomy using a cryogenically-cooled 3.2-m telescope. Its high spatial resolution and unprecedented sensitivity will enable addressing a number of key problems, ranging from the star-formation history of the Universe to the formation of planets. To reduce the mission mass, SPICA will be launched at ambient temperature and will be cooled down on-orbit using on board mechanical coolers together with an efficient radiative cooling system. This combination allows a 3-m class space telescope cooled to 6K with a moderate total weight (3700 kg). The target launch year of SPICA is around 2020 for a five-year or longer mission.

2.1.4. *Radio Observations from Space*

The space radio interferometry mission RadioAstron (Spekr-R, in Russian) was launched in July 2011 and operates properly in a highly elliptical orbit with an apogee higher than 350,000-km. This is the first of the Russian large space observatories in the Spectrum (Spektr) series to reach orbit. RadioAstron carries a 10-m segmented dish deployed in-orbit, operates at wavelengths from 1.35-cm to 92-cm and, together with ground-based radio observatories, offers an unprecedented angular resolution as fine as 10^{-6} arcsec. First light was on 27 September 2011, when Cassiopeia A was observed at 92 and 18-cm.

2.1.5. *Gravitational wave astrophysics*

The planned Laser Interferometer Space Antenna (LISA) was de-emphasized in April 2011 from the NASA mission list due to budgetary constraints. ESA is planning a full revision of the mission's concept within its Cosmic Vision L-class. LISA was thus renamed the Next Gravitational-Wave Observatory (NGO), with selection of the winning mission candidate expected in February 2012.

2.1.6. *High-energy particles*

In the domain of high-energy particle observatories, we note the continuation of the PAMELA (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) operating on the Resurs-DK1 satellite. Among the highlights of this mission is the discovery of antiprotons trapped in the geomagnetic belts circling the Earth (2011 ApJ 737, 129).

ACE (the Advanced Composition Explorer) was launched in 1997 and from its L1 location continues to detect high energy particles accelerated by the Sun, as well as particles accelerated in the heliosphere and galactic regions, with near real time 24/7 coverage of space weather, providing about one hour advance warnings of geomagnetic storms. Studies with ACE include determinations of the elemental and isotopic composition of the the solar corona, the solar wind and the local interstellar medium.

2.1.7. *Ground-based high-energy astrophysics*

In the domain of ground-based high energy observatories, we note the successful operation of the southern Auger observatory in Argentina, but regret the decision by the US not to host the northern part of the observatory. We note the revision of the HECR spectrum above 10^{18} eV presented by the Auger collaboration at the 32nd ICRC, Beijing, China, in 2011 (arXiv:1107.4809). We also note the continued operation and exciting science results from the imaging Cherenkov telescopes at the VERITAS, CANGAROO, H.E.S.S. and MAGIC sites.

2.2. *Investigating our Solar System*

Among the active space missions exploring the Solar System, CASSINI continues to observe Saturn, its rings and moons, from orbit. JUNO was launched in August 2011 to orbit Jupiter 33 times from 2016. The successful exploration of the minor planet Vesta by DAWN will be followed by a similar exploration of Ceres. An analysis of the sample container retrieved from HAYABUSA showed grains originating from the asteroid Itokawa; these are now being actively studied.

Among the inner planets, the exploration of Venus by the VENUS EXPRESS spacecraft is continuing. So is the orbital exploration of Mercury by MESSENGER; imagery from orbit showed the presence of small depressions with bright interiors and halos, often found in clusters. These could be actively forming today. Mercury will be the target of ESA and JAXA's twin BEPI-COLOMBO spacecraft in 2014.

Following a successful impact of its probe on comet Tempel 1, the DEEP IMPACT spacecraft now named EPOXI visited comet Hartley 2 in 2010. The current comet exploration flagship is ROSETTA, on its way to comet 67P/Churyumov-Gerasimenko to arrive in 2014 for orbit exploration and sample return. In the future, in 2020, NASA's OSIRIS-REx will explore the near-Earth asteroid 1999 RQ36 and return samples from its surface.

We note the constellation of spacecraft exploring Mars either from orbit or on the surface. These include the MARS ODYSSEY (launched in 2001), the MARS EXPRESS (launched also in 2001), and the MARS RECONNAISSANCE ORBITER (launched in 2006). On the surface of Mars, the OPPORTUNITY rover is still functional. In the future, the MARS SURFACE LANDER's CURIOUSITY rover is expected to launch in late-2011 and arrive on Mars in August 2012. The Mars ATMOSPHERIC and VOLATILE EVOLUTION (MAVEN) will join the Mars exploration effort in 2014. Before that, the Russian PHOBOS-GRUNT sample return and the YINGHUO-1 Mars orbiter will arrive in 2013. In 2016 the ExoMARS international mission of ESA and NASA will study trace gases in the Martian atmosphere and deploy the ESA lander and rover on the surface.

The NEW HORIZONS Pluto and Kuiper Belt exploring probe is on its way to a fly-by through Pluto's system in 2016. This is likely to be followed by the exploration (also via fly-by) of one or more Kuiper belt objects (KBOs) after passing Pluto.

Observations of the Sun are continuously carried out by the Solar and Heliospheric Observatory (SOHO) launched operating at the Sun-Earth L_1 point. SOHO operates together with the Advanced Composition Explorer (ACE) also at L_1 and with the two STEREO spacecraft, one ahead of Earth in its orbit, the other trailing behind, to provide panoramic views of almost the entire solar surface.

The HINODE satellite of JAXA (with collaborating space agencies) continues to study the solar magnetic activity. Its continued operation, past the design lifetime of three years, is important as the activity cycle ramps up to a new maximum.

SDO, the Solar Dynamics Observatory, is the first mission in NASA's Living with a Star Program and was launched in February 2010. SDO is obtaining observations of

the solar atmosphere on small angular scales and in several wavelengths simultaneously. Primary goals are to understand how the Sun's magnetic field is generated and structured and to determine how this stored magnetic energy is converted and released by the solar wind, energetic particles and intensity variations.

The Sun and the interaction of the solar wind with magnetospheres, that of the Earth in particular, are of special interest and significant space research effort is spent in this domain. In this field it is worth noting not only specific missions to study the Sun, but also the flexible retargeting of probes not originally intended for this purpose to such studies. One example is ARTEMIS, "Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun", composed of two probes originally members of the THEMIS mission in Earth orbit studying Earth's aurora, but which were redirected to the Moon to save the two probes from losing power in Earth's shade. This new mission will study the environment of Earth-Moon Lagrange points, the solar wind, the Moon plasma wake and how the Earth magnetotail and the Moon's magnetism interact with the solar wind.

Following the depletion of cryogen in WISE, the NASA Planetary division provided funding for a short mission extension in warm condition, called NEOWISE, to search for small Solar System bodies close to Earth's orbit. It is likely that the NEOWISE survey will catalog about 300,000 main-belt asteroids, of which approximately 100,000 will be new, and about 700 near-Earth objects including about 300 newly discovered.

The examples of NEOWISE and of ARTEMIS are ones to be applauded. In this era of diminishing resources available for space research, when long-planned missions are descope because of lack of funding, flexible thinking is important to maximize the science returns. One possibility that should be seriously considered by designers of future space missions is to use the cruise phase of their missions for additional science. This was very successfully done with the Voyager UVS instruments to study astronomical sources and the UV background, and could be replicated with small additional funding to the basic cost of the mission for other deep space probes.

3. Scientific meetings

The vitality of a topic can be measured by a number of metrics. One is the number of publications appearing during a certain period; another is the number and frequency of scientific meeting dedicated to this topic. We note that during the triennium period referred to in this report, numerous scientific meetings with components of Space or High-energy Astrophysics took place throughout the world. In particular several IAU Special Sessions, Joint Discussions, and Symposia at the Rio General Assembly included high energy and space topics. Meetings and workshops included those focused on science results from particular missions, techniques or energies (e.g. Chandra, XMM-Newton, Suzaku, eROSITA, Akari, far IR interferometry, astroparticle and underground physics, cosmic rays), as well as those focused on particular types of objects (e.g. "Thirty Years of Magnetars," "High Energy Phenomena in Massive Stars," "PANDA symposium on Stellar Outflows," "Supersoft X-ray Sources," "GRB Physics," "Black Hole Physics," "Feedback in Galaxies, Groups, and Clusters," "Accretion and Ejecta in AGN," "Physics of Relativistic Flows"). The many meetings, along with the vigorous space programs conducted by the world nations, indicate that the space astrophysics remains a high-interest subject.

Of particular note, we mention the success of the HST refurbishments which were celebrated with the HST III conference, held in Venice in October 2010, which presented results from the new and refurbished instruments. Having passed its 21st birthday in

space on 24 April 2011, several more years of observations are promised by the Hubble Space Telescope. However, the actual length of time provided will depend on the telescope health and on funding decisions for orbital boosts and future operations. This, combined with delays in launching ASTROSAT and the effective termination of the TAUVEK project by the Israel Space Agency, imply that the future access to observations in the UV is becoming a critical issue. This has been addressed in a number of meetings. For example, the Network of UV Astronomers (NUVA) in Europe has organized a series of workshops. The latest, held in St Petersburg in May 2010, reviewed current science results and considered the near future in the form of the Russian led World Space Observatory (WSO), which will deliver high resolution UV spectroscopy and imaging with an efficiency several times that of HST.

While the WSO and ASTROSAT will continue UV astronomical capability beyond HST, plans for a true next generation UV/optical facility with an order of magnitude improvement in capability remain uncertain. Also, apart from a handful of sounding rocket observations, there are no firm plans for any new facility in the important EUV waveband, which is yet to be explored with high effective area and spectral resolution. A workshop on “Beyond JWST: The Next Steps in UV-Optical-IR Space Astronomy”, was hosted by the Space Telescope Science Institute in March 2009. Several ideas emerged from this meeting and now appear to have merged into a project called ATLAS-T. Research in support of future UV/optical telescope technology was a priority in the recently published US Decadal survey.

On the other hand, the descriptions given above of the high-energy astrophysics field and of the IR missions indicate that these domains are relatively healthy and will provide more years of actively collecting astronomical information.

4. Closing remarks

These are exciting times to be astrophysicists. We are extremely fortunate to have operating space missions and ground based observatories that provide fantastic data across many wavelengths and allow us to address profound questions concerning the origin and evolution of the Universe and all types of celestial bodies within it. Most space missions and many ground based observatories provide rich archives, allowing broad community access to existing observations, often in conjunction with observations at other wavelengths, and often for purposes not imagined by the original observer. These treasure chests of archival data have led to many new discoveries.

In the past three years, new worlds have been discovered, along with new understandings of our solar system. We have studied the nearest star, our Sun, and the most distant galaxies, AGN and clusters. We have constrained cosmological parameters, although the nature of both Dark Energy and dark matter still elude us. There is still much to be learned and new observatories are being planned and constructed that will provide answers to many of our questions. However, the new observations, while answering old questions, will likely result in yet more questions that will require yet more observations and theoretical work to answer them. The excitement of astrophysical discoveries continues.

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