Multiwavelength Space Astronomy

A. M. Mickaelian*, G. A. Mikayelyan, H. V. Abrahamyan, and G. M. Paronyan

NAS RA V. Ambartsumian Byurakan Astrophysical Observatory (BAO), Byurakan 0213, Aragatzotn Province, Armenia

Abstract

Because the Earth's atmosphere is not transparent for the most of the electromagnetic waves, Space Astronomy was born in 1960s to complement ground-based observations and to provide us with multiwavelength data from gamma-ray to radio. Most Space observatories work in gamma-ray, X-ray, UV and IR, as well as there are also optical and other Space telescopes. We will review the most important Space telescopes: their important technical parameters, scientific results and discoveries. Among them there are (by increasing wavelengths) Fermi, Swift, INTEGRAL, ROSAT, Chandra, XMM, GALEX, Hubble, Gaia, James Webb, Herschel, WISE, Spitzer, IRAS and many others. These telescopes make the Space Astronomy truly multiwavelength and the combination with ground-based data allows us to have better understanding of the Universe and phenomena going on in its all varieties.

Keywords: *Multiwavelength Astronomy, Space Astronomy, Space Telescopes, X-ray Astronomy, UV Astronomy, IR Astronomy*

Introduction

The Earth's atmosphere is not transparent to all electromagnetic wavelengths; it is transparent only for optical and radio ones, as well as a small part of infrared (IR). This is the reason why astronomers make observations also from Space using the whole spectrum of electromagnetic waves. Moreover, optical Space telescopes are also being used to get rid from the atmosphere's absorption and other negative effects. Though first radio observations were started in 1930s and observations in some other wavelengths were carried out in 1960s, however the true Multiwavelength Space Astronomy was born in 1970s-1980s, when Space telescopes in all wavelengths were launched and studied the Universe to build up multiwavelength pictures of various astronomical objects and phenomena. These were mainly USA National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) missions, as well as some Japan Aerospace Exploration Agency (JAXA), Russian (Roscosmos), German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e. V., DLR), China National Space Administration (CNSA) and other national Space agencies' missions were accomplished.

It is also worth mentioning that the all-sky multiwavelength data at almost all wavelengths became available after 2003, when in 1996-2003 several all-sky or large area surveys (both ground-based and Space) were released, such as ROSAT, NVSS, FIRST, 2MASS, USNO-B1.0, MAPS and some others. We give in this paper an understanding on Space observatories and Space Astronomy, describe most important Space telescopes in High-Energy, UV, Optical, and IR.

High Energy Space Telescopes

Gamma-ray and X-ray astronomy are often unified as High-Energy Astronomy (HEA). In Table 1 we give the list of the most important High-Energy Space telescopes with their most important data: name, country, years of operation, energy range in keV, most important results, and number of detected sources.

In Figure 1, we give 3 most important HEA Space telescopes: Rontgensatellit (ROSAT), XMM-Newton and Chandra X-ray Observatory (CXO).

According to follow-up optical identifications of detected gamma-ray and X-ray sources, Cosmic high-energy sources are:

*aregmick@yahoo.com

doi:https://doi.org/10.52526/25792776-22.69.2-287

Table 1. Most important High-Energy Space telescopes.

Telescope	Country	Years	Energy (keV)	Results	Number of sources
Uhuru (SAS-1)	USA	1970-1973	2 – 20	Sky survey	339
HEAO-1	USA	1977-1979	0.25 – 10 000	Sky survey	842
Einstein (HEAO-2)	USA	1978-1981	0.2 – 20	Pointed deep observations	1435
EXOSAT	ESA	1983-1986	0.04 – 80	Sky survey	1210
Granat	France, Russia	1989-1999	2 – 100 000	Pointed deep observations, Sky survey	1551
CGRO	USA	1991-2000	20 – 30 000 000	Imaging, sky survey	400
ROSAT	Germany	1990-1999	0.07 – 2.4	Sky survey	124 730
ASCA (Astro-D)	Japan	1993-2001	0.4 – 10	Sky survey, spectral observations	1190
Rossi XTE (RXTE)	USA	1995-2012	2 – 250	Sky survey	321
BeppoSAX	Italy	1996-2002	0.1 – 300	Gamma bursts, broad-band spectroscopy	253
Chandra (CXO)	USA	1999-pres.	0.07 – 10	Pointed deep observations	380 000
XMM-Newton	ESA	1999-pres.	0.25 – 12	Pointed deep observations	372 728
INTEGRAL	ESA	2002-pres.	15 – 10 000	Pointed deep observations	1126
Swift	USA	2004-2008	0.2 – 150	Sky survey, gamma bursts	1256
Fermi (GLAST)	USA	2008-pres.	150 – 300 000 000	Imaging, gamma bursts	5064
NuSTAR	USA	2012-pres.	3 – 79	Deep survey for BH	498
Spektr-RG	Russia / Germany	2019-pres.	0.2 – 10	Survey, clusters of galaxies	

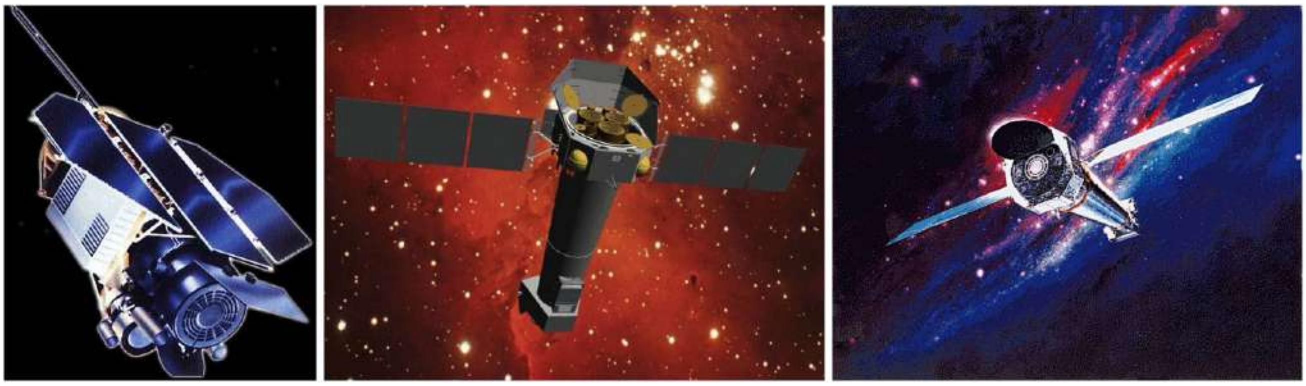

Figure 1. Three of the most important HEA Space telescopes: ROSAT, XMM-Newton and Chandra.

- Solar System bodies
- hot coronae; late-type (M) dwarfs
- white dwarfs (WD) and hot subdwarfs (sd)
- X-ray binaries; intermediate mass X-ray binaries
- cataclysmic variables (CV)
- magnetars
- Supernovae remnants (SNR)
- bright galaxies
- Active Galactic Nuclei (AGN) and Starburst (SB) Galaxies
- blazars (part of AGN)
- clusters of galaxies

Ultraviolet Space Telescopes

In Table 2 we give the list of the most important Ultraviolet (UV) Space telescopes with their most important data: name, country, years of operation, wavelength range in A, most important results, and number of detected sources.

In Figure 2, we give 3 of the most important UV Space telescopes: IUE, FUSE and GALEX.

doi:https://doi.org/10.52526/25792776-22.69.2-287

Table 2. Most important UV Space telescopes.

Space Telescope	Country	Years	Wavelength range λ ($\AA$)	Results	Number of objects
OAO 2	USA	1968-1973	1050 – 4250	Comets, Novae	
OAO 3 (Copernicus)	USA	1972-1981	1047 – 1055	HR spectra, pulsars	
Orion	USSR	1971	2000 – 3800	UV spectra	
Orion-2	USSR	1973	2000 – 3000	UV spectra	900
ANS	USA / Neth.	1974-1976	1500 – 3300	Images, spectra	3 573
International Ultraviolet Explorer (IUE)	USA / ESA	1978–1996	1150 – 3200	Images, spectra	110 033
Astron	USSR	1983-1989	1500 – 3500	Supernovae, comets	203 592
Glazar	USSR	1987	1640	UV emission of stars	
Hubble Space Telescope (HST)	USA / ESA	1990-pres.	1150 – 17000	Imaging, spectra	
EUVE	USA	1992-2001	70 – 760	All-sky survey	801
FUSE	USA	1999-2007	905 – 1195	Universal deuterium	5 061
Galaxy Evolution Explorer (GALEX)	USA	2003-2013	1350 – 2800	Sky survey	82 992 086

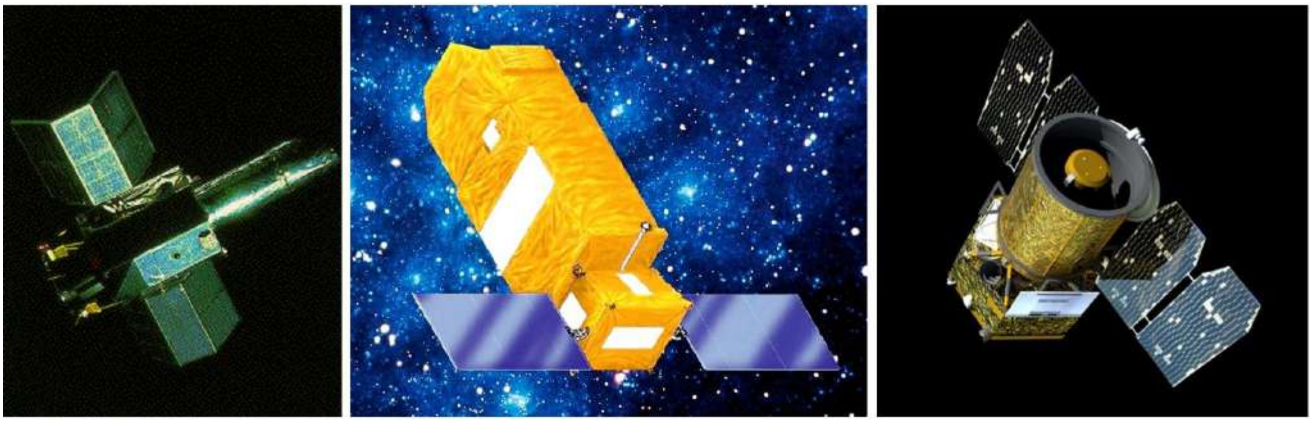

Figure 2. Three of the most important UV Space telescopes IUE, FUSE and GALEX.

Optical Space Telescopes

Though optical wavelengths are accessible from ground as well, however, the Earth's atmosphere strongly affects the astronomical observations, as the light is being absorbed and distorted due to turbulence resulting reduction of the resolution. Hence, Space observations are deeper and have much higher resolution; therefore, especially the astrometric missions have great success compared to the Earth ground-based observations. Along with HIPPARCOS and Gaia astrometric missions for all-sky surveys, optical Space telescopes Kepler, TESS and some others were aimed at detecting exoplanets, also due to high astrometric accuracy. We give in Table 3 the list of the most important optical Space telescopes with their most important data: name, country, years of operation, wavelength range in A, most important results, and number of detected objects. Note, James Webb Space Telescope (JWST), the largest Space telescope with a diameter of the mirror 6.5m and with a collecting area of 25.4 m^2, is recent and the number of detected objects is just preliminary.

Table 3. Most important optical Space telescopes.

Space Telescope	Country	Years	Wavelength range λ ($\AA$)	Results	Number of objects
HIgh Precision PARallax COllecting Sat. (HIPPARCOS)	ESA	1989-1993	visible	Astrometry	2 539 913
Hubble Space Telescope (HST)	USA / ESA	1990-pres.	1150 – 17000	Imaging, spectra	
Kepler Space Telescope	USA	2009-2013	4300 – 8900	Exoplanets	5 011
Global Astrometric Interferom. for Astrophysics (Gaia)	ESA	2013-pres.	3200 – 10000	Astrometry, spectra	1 811 709 771
Transiting Exoplanet Survey Satellite (TESS)	USA	2018-pres.	visible	Exoplanets	5 000
James Webb Space Tel. (JWST)	USA / ESA	2021-pres.	6000 – 283 000	Cosmology, exoplanets	78

In Figure 3, we give 3 of the most important optical Space telescopes: HST, Gaia and JWST.

Infrared Space Telescopes

Only the nearest part of the Infrared (IR) range is accessible from the Earth, typically up to 5.5 μm, as well as our atmosphere is somewhat transmitting also the range 8-14 μm. Anyway, the IR Space astronomy is one of the most important among all ranges, as many new discoveries have been accomplished in these wavelengths. In Table 4 we give the list of the most important IR Space telescopes with their most important data: name, country, years of operation, wavelength range in μm, most important results, and number of

doi:https://doi.org/10.52526/25792776-22.69.2-287

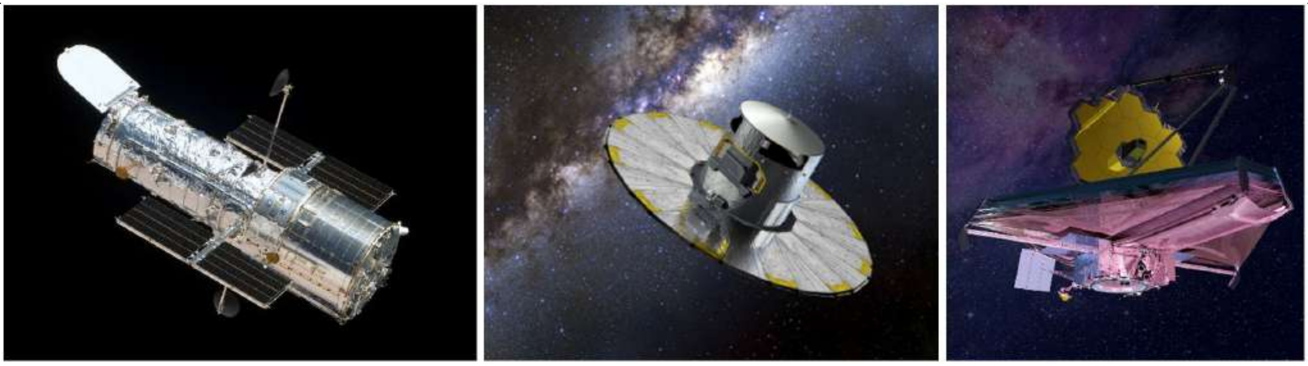

Figure 3. Three of the most important optical Space telescopes: HST, Gaia and JWST.

detected sources. Among them, there are two biggest Space telescopes: recently launched JWST with its 6.5m diameter mirror and Herschel with its 3.5m diameter mirror. Only these two Space telescopes are larger than HST (2.4m), which is operating since 1990.

Table 4. Most important IR Space telescopes.

Telescope or project	Countries	Years	λ (μm)	Results	Number of sources
Infrared Astronomical Satellite (IRAS)	USA	1983-1983	8 – 120	Sky survey	405 769
Infrared Space Observatory (ISO)	ESA	1995-1998	2.5 – 240	IR spectra	~ 30 000
Spitzer Space Telescope (SST)	USA	2003-2020	3 – 180	IR deep images and spectra	4 261 028
AKARI (Astro-F)	Japan	2006-2011	7 – 180	Sky survey	1 298 044
Herschel Space Observatory (HSO)	ESA / USA	2009-2013	55 – 672	Far IR sources	8 223 000
Wide-field Infrared Survey Explorer (WISE)	USA	2009-2013	3 – 28	Sky survey	563 921 584
JWST	USA / ESA	2021-pres.	0.6 – 283	Cosmology, exoplanets	78

In Figure 4, we give 3 of the most important IR Space telescopes: IRAS, Spitzer and Herschel.

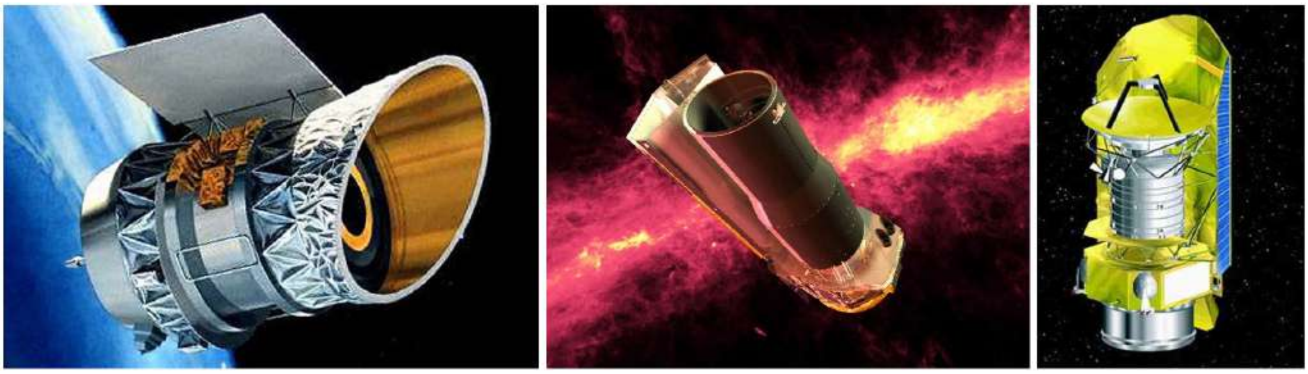

Figure 4. Three of the most important IR Space telescopes: IRAS, Spitzer and Herschel.

According to all these observations, many IR sources have been revealed and many have been identified with optical counterparts, different kinds of objects:

- In Near-IR (NIR) (wavelength range from 0.76-1 to 5 μm, temperature range from 740 to 3000-5200 K), the main emitters are cold red stars, stellar envelopes, planetary nebulae;
- In Mid-IR (MIR) (wavelength range from 5 to 25-40 μm, temperature range from 92.5-140 to 740 K), the main emitters are planets, comets and asteroids, stellar radiation heated dust, protoplanetary disks, gas-dust nebulae;
- In Far-IR (FIR) (wavelength range from 25-40 to 200-350 μm, temperature range from 10.6-18.5 to 92.5-140 K), the main emitters are cold gas radiation, central regions of galaxies, very cold molecular clouds.

doi:https://doi.org/10.52526/25792776-22.69.2-287

Microwave Space Telescopes

Cosmic Microwave Background radiation (CMB, CMBR) is the most important witness of the Big Bang, the main cosmological theory, also called theory of the Hot Universe. Space missions working at microwave range are aimed at detecting in details as much as possible the CMB, to reveal its temperature, anisotropy, etc. We give in Table 5 the list of the most important Microwave Space telescopes with their most important data.

Table 5. Most important Microwave Space telescopes.

Telescope or project	Countries	Years	λ (μm)	Results
Cosmic Background Explorer (COBE)	USA	1989-1993	1 – 10 000	Sky survey, CMBR
Wilkinson Microwave Anisotropy Probe (WMAP)	USA	2001-2010	3 200 – 13 000	Sky survey, CMBR
Planck Space Observatory	ESA	2009-2013	300 – 11 100	Sky survey, CMBR

In Figure 5, we give the most important Microwave Space telescopes: COBE, WMAP and Planck.

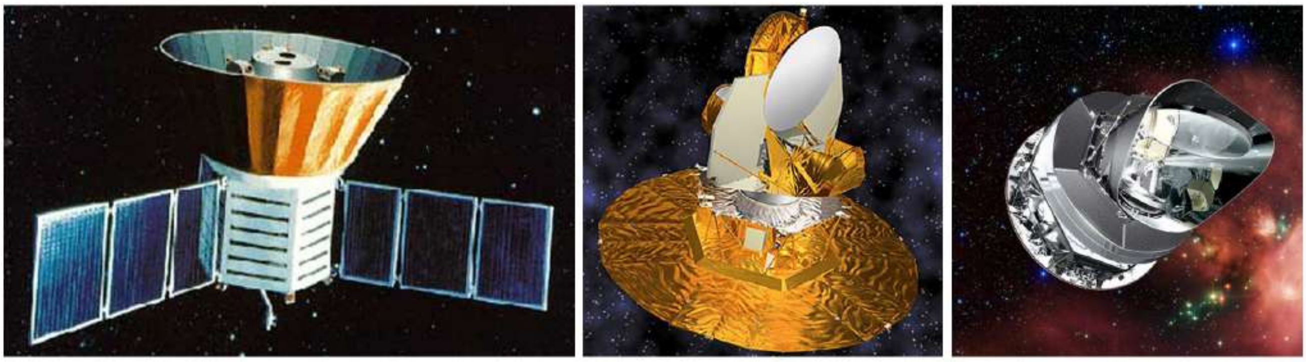

Figure 5. Most important Microwave Space telescopes: COBE, WMAP and Planck.

Scientific results at BAO based on Space telescopes data

Modern astronomy is full of discoveries based especially on Space telescopes data. Many investigations in the Byurakan Astrophysical Observatory (BAO) are also based on results from IRAS, HST, ROSAT, Spitzer, XMM, Chandra, Herschel, Gaia, and other Space telescopes. Here we give the scientific results by our "Astronomical Surveys" research team based on Space telescopes data. The following results may be outlined:

- Revelation of 1577 IRAS unidentified IR sources; 1279 galaxies (BIG objects) and 287 (BIS) (Mickaelian & Sargsyan (2004); Mickaelian & Gigoyan (2006)).
- New bright AGN (Seyferts and LINERs) and ULIRGs among BIG objects (Mickaelian et al. (2002); Mickaelian & Sargsyan (2010)). Dozens of new pairs and multiple galaxies among IRAS sources (Mickaelian (2007)). Estimation of the maximum IR luminosity of a single spiral galaxy (10^{12}L) (Mickaelian (2001)).
- Discovery of IRAS F18187+6304: a puzzling PMS emission line star with circumstellar envelope among BIS objects (Rossi et al. (2010); Gaudenzi et al. (2017a); Gaudenzi et al. (2017b)).
- Revelation of 3212 ROSAT FSC X-ray sources (Véron-Cetty et al. (2004)). New bright AGN (QSOs and Seyferts) among X-ray sources.
- Optical identification of ROSAT sources and estimation of the abundance of various types of objects among X-ray sources. Revelation of 2791 ROSAT FSC X-ray sources (BHRC objects) (Mickaelian et al. (2006)). Pairs and multiple galaxies among ROSAT sources, discovery of new types of X-ray sources: interacting galaxies.

doi:https://doi.org/10.52526/25792776-22.69.2-287

- Mickaelian's observational project on study of high-luminosity IR galaxies was carried out on IR Spitzer Space Telescope (SST) in collaboration with Cornell University (Ithaca, N.Y., USA) team (Sargsyan et al. (2008)). 32 highest IR/opt flux ratio extragalactic sources selected from IRAS FSC and observed with SST. Study of their NIR-MIR spectra. Discovery of the highest IR/opt flux ratio (40-1000) extragalactic objects.

- Mickaelian's observational project on study of IR excess galactic stars was carried out on IR Spitzer Space Telescope (SST) in collaboration with Cornell University (Ithaca, N.Y., USA) team (Hovhannisyan et al. (2009)). Study of 237 Spitzer Space Telescope (SST) stellar sources in Boötes and FLS. Discovery of 21 hot debris disk stars among Spitzer sources.

Summary

Multiwavelength Space Astronomy was a real revolution in Astronomy/Astrophysics and is still being extremely important for further advanced studies. This is especially outstanding in those wavelength ranges, where the Earth atmosphere is not transparent for photons. Many new discoveries in different wavelength ranges related to Solar System objects, stars, nebulae, star-formation regions, galaxies, clusters of galaxies, Cosmology, and exoplanets were made, as well as the combination of various wavelength data gives a new possibility for further more efficient studies of the Universe. The Astrophysical Virtual Observatories (AVOs, VOs) appeared and were developed mainly due to the development of Space Astronomy, as most of the new wavelength ranges appeared to be intensely explored after the Space era. Still, the vast majority of objects in astronomy has been discovered in the optical range (some 2.4 billion objects out of the total 3 billion in all wavelengths), however it is important to have an overall understanding for any of objects and combine gamma-ray, X-ray, UV, optical, IR, submm/mm and radio data, as well as various methods of observations and even non-electromagnetic information, leading from Multiwavelength (MW) Astronomy to real Multimessenger (MM) Astronomy.

In Figure 6, we give the distribution of ESA's Space telescopes by wavelength range, both past, operational and future ones.

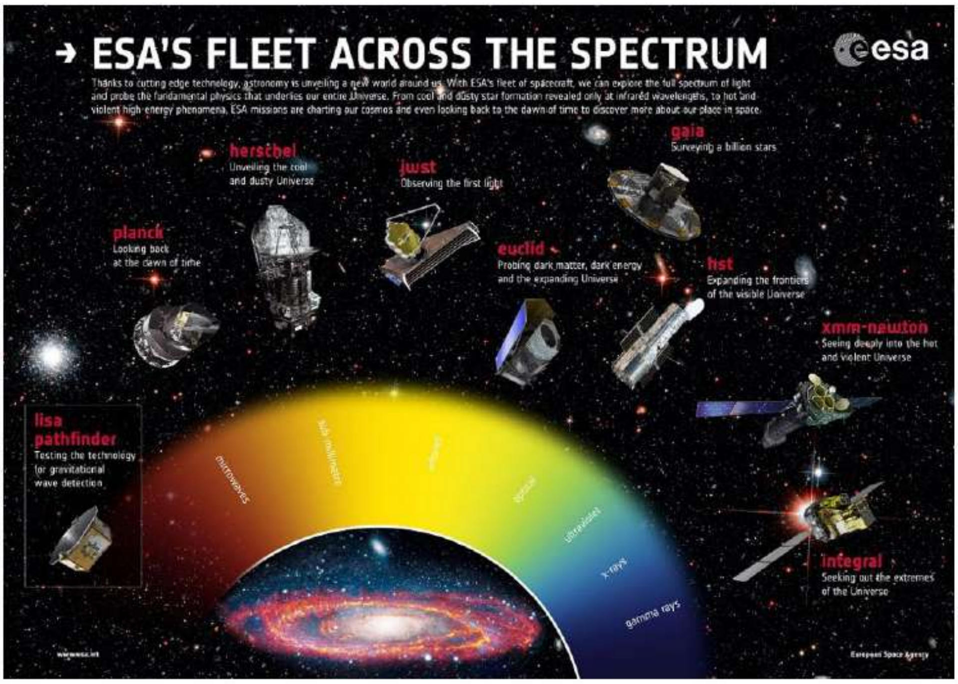

Figure 6. ESA's fleet across the spectrum; ESA's multiwavelength Space missions.

Acknowledgements

This work was partially supported by the Republic of Armenia Ministry of Education, Science, Culture, and Sports (RA MESCS) Committee of Science, in the frames of the research projects No. 15T-1C257 and 21AG-1C053. This work was made possible in part by research grants from the Armenian National Science and Education Fund (ANSEF) based in New York, USA (grants astroex-4193, astroex-4195, astroex-2347 and astroex-2597).

doi:https://doi.org/10.52526/25792776-22.69.2-287

References

1988, Infrared Astronomical Satellite (IRAS) Catalogs and Atlases.Volume 7: The Small Scale Structure Catalog. Vol. 7

1997, The HIPPARCOS and TYCHO catalogues. Astrometric and photometric star catalogues derived from the ESA HIPPARCOS Space Astrometry Mission ESA Special Publication Vol. 1200

Abdollahi S., et al., 2020, Astrophys. J. Suppl. Ser. , 247, 33

Abdollahi S., et al., 2022, Astrophys. J. Suppl. Ser. , 260, 53

Abrahamyan H. V., Mickaelian A. M., Knyazyan A. V., 2015, Astronomy and Computing, 10, 99

Ajello M., Greiner J., Kanbach G., Rau A., Strong A. W., Kennea J. A., 2008, Astrophys. J. , 678, 102

Bailer-Jones C. A. L., Rybizki J., Fouesneau M., Mantelet G., Andrae R., 2018, Astron. J. , 156, 58

Beitia-Antero L., Gómez de Castro A. I., 2016, Astron. Astrophys. , 596, A49

Bianchi L., Herald J., Efremova B., Girardi L., Zabot A., Marigo P., Conti A., Shiao B., 2011, Astrophys. Space. Sci. , 335, 161

Bottacini E., Ajello M., Greiner J., 2012, Astrophys. J. Suppl. Ser. , 201, 34

Bowyer S., Lampton M., Lewis J., Wu X., Jelinsky P., Malina R. F., 1996, Astrophys. J. Suppl. Ser. , 102, 129

Bystrov N. F., Polojentsev D. D., Potter H. I., Yagudin L. I., Zallez R. F., Zelaya J. A., 1994, Bulletin d'Information du Centre de Donnees Stellaires, 44, 3

Cutri R. M., et al., 2012, Explanatory Supplement to the WISE All-Sky Data Release Products, Explanatory Supplement to the WISE All-Sky Data Release Products

Davison P. J. N., Culhane J. L., Mitchell R. J., Fabian A. C., 1975, Astrophys. J. Lett. , 196, L23

Dezalay J. P., Barat C., Talon R., Sunyaev R., Terekhov O., Kuznetsov A., 1993, in Friedlander M., Gehrels N., Macomb D. J., eds, American Institute of Physics Conference Series Vol. 280, Compton Gamma-ray Observatory. pp 783–787, doi:10.1063/1.44220

Evans I. N., et al., 2010, Astrophys. J. Suppl. Ser. , 189, 37

Evans I. N., et al., 2014, VizieR Online Data Catalog, p. IX/45

Flores H., et al., 1999, Astrophys. J. , 517, 148

Forman W., Jones C., Cominsky L., Julien P., Murray S., Peters G., Tananbaum H., Giacconi R., 1978, Astrophys. J. Suppl. Ser. , 38, 357

Gaia Collaboration et al., 2018, Astron. Astrophys. , 616, A1

Gaudenzi S., Nesci R., Rossi C., Sclavi S., Gigoyan K. S., Mickaelian A. M., 2017a, Rev. Mex. Astron. Astrofis. , 53, 449

Gaudenzi S., Nesci R., Rossi C., Sclavi S., Gigoyan K. S., Mickaelian A. M., 2017b, Rev. Mex. Astron. Astrofis. , 53, 507

Geach J. E., et al., 2017, Mon. Not. R. Astron. Soc. , 465, 1789

Giacconi R., et al., 1979, Astrophys. J. , 230, 540

Golenetskii S. V., et al., 1991, Advances in Space Research, 11, 125

Güdel M., et al., 2007, Astron. Astrophys. , 468, 353

Haakonsen C. B., Rutledge R. E., 2009, Astrophys. J. Suppl. Ser. , 184, 138

Herschel Point Source Catalogue Working Group et al., 2020, VizieR Online Data Catalog, p. VIII/106

Hovhannisyan L. R., et al., 2009, Astron. J. , 138, 251

Ishihara D., et al., 2010, Astron. Astrophys. , 514, A1

Koss M. J., et al., 2022, Astrophys. J. Suppl. Ser. , 261, 2

Lansbury G. B., et al., 2017, Astrophys. J. , 836, 99

Malizia A., Bassani L., Bazzano A., Bird A. J., Masetti N., Panessa F., Stephen J. B., Ubertini P., 2012, Mon. Not. R. Astron. Soc. , 426, 1750

Malizia A., Bassani L., Stephen J. B., Bazzano A., Ubertini P., 2020, Astron. Astrophys. , 639, A5

Mickaelian A. M., 2001, Astrophysics, 44, 33

Mickaelian A. M., 2007, in Combes F., Palouš J., eds, Vol. 235, Galaxy Evolution across the Hubble Time. pp 225–225, doi:10.1017/S1743921306006314

Mickaelian A. M., Gigoyan K. S., 2006, Astron. Astrophys. , 455, 765

Mickaelian A. M., Sargsyan L. A., 2004, Astrophysics, 47, 213

Mickaelian A. M., Sargsyan L. A., 2010, Astrophysics, 53, 483

Mickaelian A. M., Balayan S. K., Hakopian S. A., 2002, in Green R. F., Khachikian E. Y., Sanders D. B., eds, Astronomical Society of the Pacific Conference Series Vol. 284, IAU Colloq. 184: AGN Surveys. p. 217

Mickaelian A. M., Hovhannisyan L. R., Engels D., Hagen H. J., Voges W., 2006, Astron. Astrophys. , 449, 425

Moshir M., et al. 1990, IRAS Faint Source Catalogue, p. 0

Revnivtsev M., Sazonov S., Jahoda K., Gilfanov M., 2004, Astron. Astrophys. , 418, 927

Rossi C., et al., 2010, Memorie della Societa Astronomica Italiana Supplementi, 14, 127

Sanford P. W., Ives J. C., Bell Burnell S. J., Mason K. O., Murdin P., 1975, Nature. , 256, 109

Sargsyan L., Mickaelian A., Weedman D., Houck J., 2008, Astrophys. J. , 683, 114

Tanaka Y., Inoue H., Holt S. S., 1994, Publ. Astron. Soc. Jpn. , 46, L37

Treves A., et al., 1980, Astrophys. J. , 242, 1114

Tueller J., Mushotzky R. F., Barthelmy S., Cannizzo J. K., Gehrels N., Markwardt C. B., Skinner G. K., Winter L. M., 2008, Astrophys. J. , 681, 113

Verbunt F., van Gent R. H., 2011, Astron. Astrophys. , 530, A93

Véron-Cetty M. P., et al., 2004, Astron. Astrophys. , 414, 487

Voges W., et al., 2000, IAU Circ., 7432, 3

Waskett T. J., Eales S. A., Gear W. K., McCracken H. J., Brodwin M., Nandra K., Laird E. S., Lilly S., 2004, Mon. Not. R. Astron. Soc. , 350, 785

Wesselius P. R., van Duinen R. J., de Jonge A. R. W., Aalders J. W. G., Luinge W., Wildeman K. J., 1982, Astron. and Astrophys. Suppl. Ser. , 49, 427

White N. E., Mason K. O., Sanford P. W., Murdin P., 1976, Mon. Not. R. Astron. Soc. , 176, 201

Wood K. S., et al., 1984, Astrophys. J. Suppl. Ser. , 56, 507

Yamamura I., Makiuti S., Ikeda N., Fukuda Y., Oyabu S., Koga T., White G. J., 2010, VizieR Online Data Catalog, p. II/298

von Kienlin A., et al., 2020, Astrophys. J. , 893, 46

doi:https://doi.org/10.52526/25792776-22.69.2-287