U.K. Space Missions and Policy

The UK's future with ESA as seen through an STFC astronomy priority lens

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Abstract Astronomy and astrophysics research has long been a strength in the UKs academic and research portfolio. Astronomy and astrophysics missions that are launched into space often have deep UK academic involvement including NASA and ESA missions. In particular, the UK Space Agency (UKSA) is responsible for much of the UK astrophysics space mission programme, while the science strategy, early technology, data challenges and exploitation are all within the remit of Science and Technology Facilities Council (STFC). Here, we addres the very specific issue of how the STFC astrophysics priorities align with the ESA Science mandatory programme and specifically the ESA *Cosmic Vision: Space Science for Europe 2015–2025* campaign.

Overview With the new UK Government, the incoming Budget and the European Space Agency (ESA) holding the next Ministerial Council meeting in November 2025, now is a critical time to understand the scope of the U.K.'s future with ESA in general and as seen through the lens of the Science and Technology Facilities Council (STFC) in particular. Here we suggest five STFC astrophysics priorities (given in no particular order) and how ESA missions have recently, or are imminently coming online to address these.

Direct influence is taken from the STFC Astronomy Advisory Panel Roadmap 2022.[1] The UK Space Agency (UKSA) is responsible for much of the UK astrophysics space mission programme, while the science strategy, early technology, data challenges and exploitation are all within the remit of STFC. In this document we are ruthlessly narrow in scope, and note how STFC astronomy priorities line-up with the ESA Science mandatory programme and specifically the ESA *Cosmic Vision: Space Science for Europe 2015–2025* campaign. Below we give a top-level view of the five STFC astrophysics priorities. Table 1 gives the current mission portfolio for the Cosmic Vision campaign while Table 2 maps these priorities to the facilities available to STFC.

Cosmology, Dark energy and Dark matter We do not know the nature of the vast majority of what constitutes the Universe. 'Dark Energy' is thought to be causing the expansion of the Universe to accelerate, while 'Dark Matter' is understood to be fundamental to structure formation for galaxies but does not interact with light or other electromagnetic radiation. Although we know that the quantity of the energy-density of the Universe is 26% dark matter and 68% dark energy, the exact nature of both dark matter and dark energy remains a mystery.

The objective of the ESA *Euclid* mission is to better understand dark energy and dark matter by accurately measuring the accelerating expansion of the universe. The recently selected *Analysis of Resolved Remnants of Accreted galaxies as a Key Instrument for Halo Surveys* (ARRAKIHS) is a planned mission to study the dark matter haloes of galaxies.

The Gravitational Universe The first direct observation of gravitational waves made by the LIGO gravitational wave detectors in the USA of the event GW150914 in 2015 forever changed the way we observe and listen to the Universe.[2] Gravitational waves were predicted in 1916 by Albert Einstein on the basis of his general theory of relativity as ripples in spacetime. Gravitational waves transport energy as gravitational radiation and are radiated by massive objects whose motion involves changes in acceleration given the system has some non-spherically symmetry. Critically, gravitational waves allow you to test theories of gravity and are not diminished to nearly the same extent as EM radiation, experiencing very little absorption even over very large distances. This will allow studies of the extremely early Universe.

The ESA Laser Interferometer Space Antenna (LISA) will be the first space-based gravitational-wave observatory and it aims to detect and measure gravitational waves from astronomical sources directly using laser interferometry. LISA has a range of science goals and is able to access a frequency of gravitational waves that is not possible on Earth.

The Early Universe: Probing Cosmic Dawn The Early Universe, usually defined as the epoch after cosmic microwave background emission (around ≈370,000 years after the Big Bang)

[1] DOI: 10.48550/arXiv.2301.05457v1

[2] The 2017 Nobel Prize in Physics was awarded to Rainer Weiss, Kip Thorne and Barry Barish for their role in the direct detection of gravitational waves.There is a strong case that Prof. Ronald Drever, alma mater University of Glasgow would have won the Nobel Prize in the place of Barry Barish had he not died before the Nobel Committee made their decision.

to about 1 billion years after the Big Bang is the era when the first stars and galaxies are able to form.[3] This is the epoch of the Universe where conditions become suitable for the first stars and the first early galaxies to form. However, the abundance of neutral hydrogen at this epoch means the Universe remains relatively opaque and direct observations are difficult.

Operating to 2μm in the near-infrared, ESA *Euclid* mission will deliver information on the Early Universe and 'cosmic dawn' when the first stars ignited and shone.

STARS AND GALAXIES: INTERCONNECTED AND SYMBIOTIC SYSTEMS The Universe is characterized by an enormous range of physical scales and hierarchy in structure, from stars and planetary systems to galaxies and a cosmological web of complex filaments. The quest to understand these interconnected and symbiotic systems, including how stars and galaxies are formed, live and die remains a key scientific endeavour.

Euclid is already delivering information on galaxy evolution while ESA *NewAthena* is an X-ray observatory that will address a range of open scientific questions. This includes: determining the mechanisms regulating the cosmological co-evolution of accreting black holes and their host galaxies; constraining the kinematics of hot gas and metals in massive halos (galaxy clusters and groups); constraining supernova explosion mechanisms and studying stellar-planet interactions through the magnetic activity in exoplanet-hosting systems.

THE ORIGIN OF LIFE "Are we alone in the Universe?" remains one of, if not the most fundamental questions that humans can ask. Is there extra-terrestrial life in our cosmic neighbourhood? And if there is, what form does it take? Over the course of the last 30 or so years, astronomers have confirmed over 5,500 exoplanets - planets orbiting stars other than the Sun, with nearly 1,000 stellar systems being multi-planetary. The task at hand is further discovery, but also characterization of exoplanets to understand in detail if there are signatures of life.

ESA CHaracterising ExOPlanets Satellite (CHEOPS) is an ongoing missionto determine the size of known extrasolar planets, which will allow the estimation of their mass, density, composition and their formation. ESA PLAnetary Transits and Oscillations of stars (PLATO) will search for exoplanets and measure stellar oscillations. ESA Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) is a space observatory which will observe transits of nearby exoplanets. The primary science goal of the ESA Comet Interceptor mission is "to characterise, a dynamically-new comet, including its surface composition, shape, structure, and the composition of its gas coma." ESA Jupiter Icy Moons Explorer (JUICE) is an interplanetary spacecraft on its way to orbit and study three icy moons of Jupiter: Ganymede, Callisto, and Europa. These planetary-mass moons are planned to be studied because they are thought to have beneath their frozen surfaces significant bodies of liquid water.

[3] For some perspective, imagine the Universe today is an 80 year old person. 370,000 years after the Big Bang is the equivalent to seeing the 1-day old baby photo of the elderly human. 1 billion years for the Universe is then roughly a couple of months before the human's 6th birthday.

Table 1: Overview of ESA Missions and Their Scientific Themes

MISSION	CLASS	SCIENCE THEME	LAUNCH
CHEOPS	S1	Measure known exoplanets size	18 Dec 2019
Solar Orbiter	M1	Close-up observations of the Sun	10 Feb 2020
Euclid	M2	Dark energy and dark matter	01 Jul 2023
JUICE	L1	Explore the Jupiter system	14 Apr 2023
SMILE	S2	Interaction between Earth's magnetosphere and solar wind	Late 2025
PLATO	M3	Search for exoplanets and measure stellar oscillations	2026
ARIEL	M4	Nearby exoplanet chemical composition and physical conditions	2029
Comet Interceptor	F1	Study a long-period comet or an interstellar object	2029
EnVision	M5	High-resolution radar mapping of the surface of Venus and atmospheric studies	2031
ARRAKIHS	F2	Dwarf galaxies and stellar streams	Early 2030s
NewAthena	L2	High-energy Universe	2035
LISA	L3	Gravitational Universe	2035

Table 2: STFC Astrophysics Science Priorities and ESA Cosmic Vision Portfolio

STFC SCIENCE PRIORITY	ESA MISSION
Gravitational Universe	LISA
The Early Universe	*Euclid*
Dark Energy & Dark Matter	*Euclid*
	ARRAKIHS
Stars and Galaxies	*Euclid*
	NewAthena
	ARRAKIHS
The Origin of Life	CHEOPS
	JUICE
	Comet Interceptor
	PLATO
	ARIEL