



Enduring Quests Daring Visions

NASA Astrophysics in the Next Three Decades



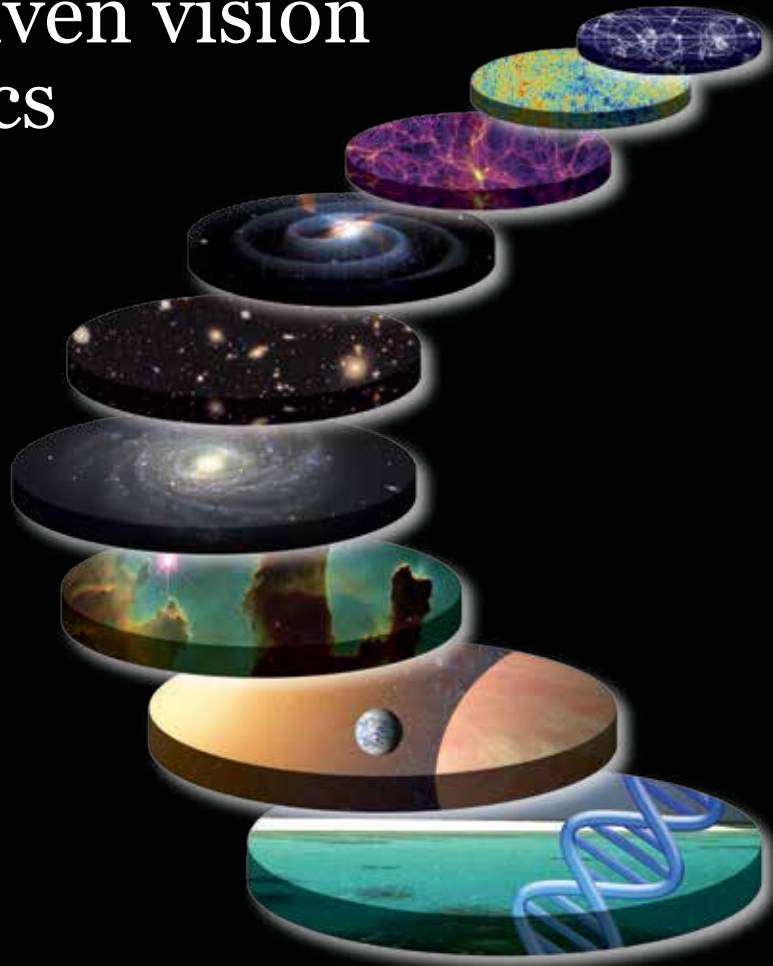
A 30-year science-driven vision for NASA Astrophysics

The past three decades have seen prodigious advances in astronomy and astrophysics. But where do we go from here? This roadmap presents a science-driven 30-year vision for the future of NASA Astrophysics that builds on our remarkable progress by addressing three defining questions:

- Are we alone?
- How did we get here?
- How does the universe work?

Seeking answers to these age-old questions are Enduring Quests of humankind. The coming decades will see giant strides forward in finding earthlike habitable worlds (exoEarths), in understanding the history of star and galaxy formation and evolution, and in teasing out the fundamental physics of the cosmos.

Different astronomical phenomena are typically most prominent in distinct regions of the electromagnetic spectrum: young, dust-enshrouded stars in the far-infrared; older stars and galaxies in visible and near-optical wavelengths; star-forming regions in the ultraviolet; and the million-degree gas of galaxy clusters and black hole accretion disks in X-rays. In addition to spanning the electromagnetic spectrum, the roadmap missions will open a revolutionary new window on the cosmos by detecting gravitational waves, ripples of space-time that emanate from colossal events like the merging of two black holes and radiate throughout the observable universe.



These scientific investigations and their enabling space missions are described here in three broad categories of time: the Near-Term Era, defined by missions that are currently flying or planned for the coming decade; the Formative Era, with notional missions (referred to here as “Surveyors”) that could be designed and built in the 2020s; and the Visionary Era of technologically advanced missions (referred to as “Mappers”) for the 2030s and beyond.



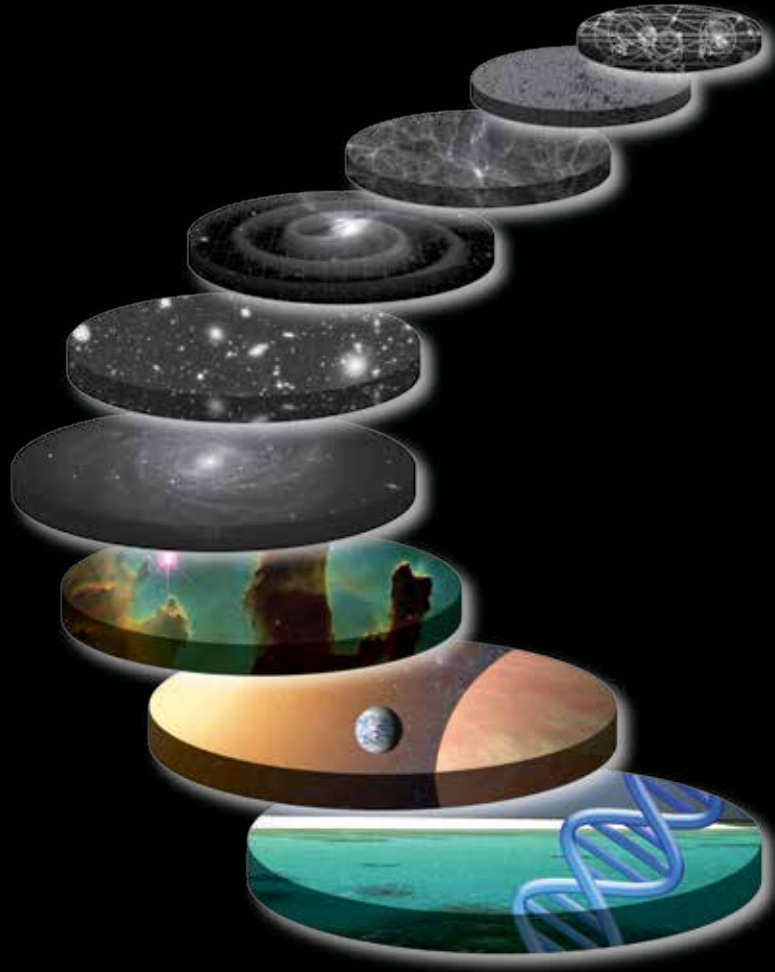
Are we alone?

Throughout human history, we have yearned to comprehend our universe and understand our place within it. The next stage in this Quest—and possibly the most exciting one—opened with the discovery of planets around other stars in the mid-1990s and continues today with the work of NASA’s Kepler mission, which has discovered thousands of candidate exoplanets.

In the Near-Term Era, we will determine the prevalence of rocky exoplanets in habitable zones using Kepler and follow-on missions. We will study the diversity and characteristics of a wide variety of exoplanets using the flagship James Webb Space Telescope. Astrobiology investigations will help us better understand potential life signs on other worlds.

In the Formative Era, a large ultraviolet-optical-infrared space telescope, the LUVOIR Surveyor, will confirm whether rocky exoplanets in the habitable zones of nearby stars really have life-sustaining surface conditions. This mission could possibly even find indirect atmospheric signs of surface life.

An ambitious ExoEarth Mapper space mission in the Visionary Era could provide direct evidence of continents, oceans, and surface life on nearby worlds similar to Earth. Achieving this goal will require space-based interferometry, a technique where the power of several smaller, widely separated telescopes achieves the resolution of a single huge telescope with a diameter comparable to the separations between the small telescopes.



Formative Era (2020–2030)

LUVOIR Surveyor

Visionary Era (2030+)

ExoEarth Mapper



How did we get here?

In the Near-Term Era, we will learn new details about the life cycles of stars and the evolution of the elements, complete an inventory of the accretion events that built up our own galaxy, and image the first galaxies in the universe. These efforts will use both ground- and space-based facilities, including the James Webb Space Telescope.

In the Formative Era, we'll map the chemical evolution of nearby planetary environments with the LUVOIR Surveyor and study how water flows into the inner regions of planet-forming disks with a Far-IR Surveyor. The LUVOIR Surveyor also will unravel the "archaeology" of our own galaxy, letting us trace its accretion of smaller galaxies, build a movie of how the disk spins and the spiral arms work, and establish the chemical composition of gas that formed all components of the Milky Way. We will capture similar information about other galaxies as well. An X-ray Surveyor will enable us to measure the spins of black holes in the nearby universe to expose the inner workings of quasars and other galaxies powered by supermassive black holes. A Gravitational Wave Surveyor will record the mergers of massive black holes.

In the Visionary Era, a parallel set of Mapper missions will extend these studies to slices of space throughout cosmic time. The ExoEarth Mapper will directly image the accretion disk around nearby black holes. From the moon's far side, the Cosmic Dawn Mapper radio array will reveal structure present during the dark ages, before the first stars shone, and the epoch of reionization.

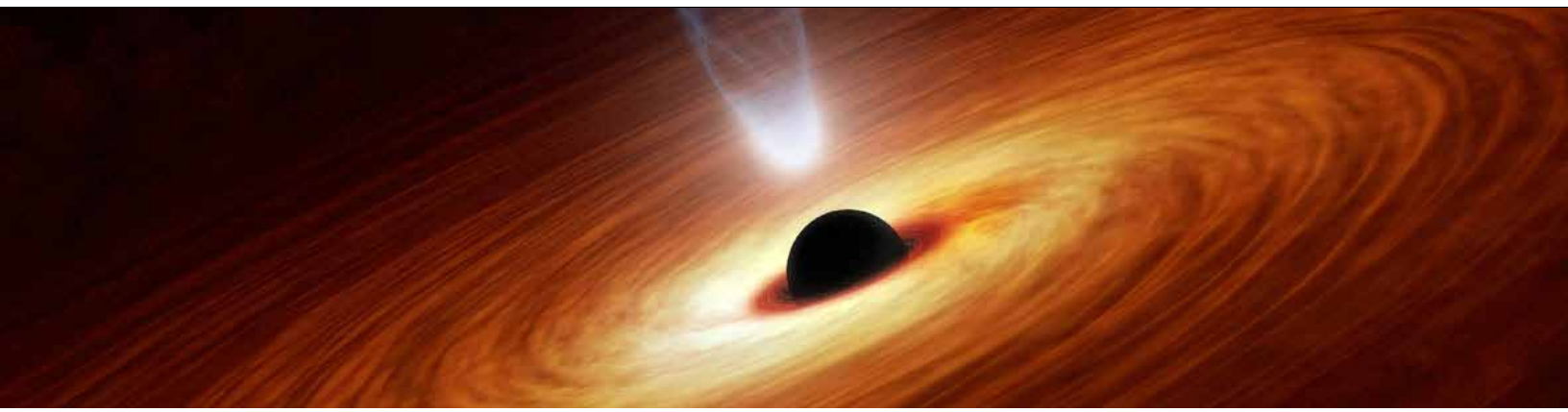


Formative Era (2020–2030)

Far-IR Surveyor
LUVOIR Surveyor
X-ray Surveyor
Gravitational Wave Surveyor

Visionary Era (2030+)

X-ray Mapper
Gravitational Wave Mapper
ExoEarth Mapper
Cosmic Dawn Mapper



How does our universe work?

Modern cosmological observations have provided a powerful empirical basis for addressing questions about cosmic origins, but our answers remain far from complete. In one of the most counterintuitive scientific discoveries of recent decades, we have learned that the expansion of the universe is speeding up rather than slowing down. The driving force behind this, called dark energy, is not yet understood.

The cosmic microwave background (CMB) is the afterglow of our universe's birth. In the Formative Era, a CMB Polarization Surveyor will provide detailed measurements of "twists" in this light caused by the presence of gravitational waves. The X-ray Surveyor will measure the properties of neutron stars and test predictions of general relativity in the vicinity of black holes. The Gravitational Wave Surveyor will measure mergers of supermassive black holes throughout the universe and test predictions of their physics and of the polarization of gravity waves.

In the Visionary Era, the Gravitational Wave Mapper will measure the cosmic expansion history to ultra-high precision using hundreds of thousands of merging neutron stars and black holes and directly detect gravitational waves from the early universe. The Cosmic Dawn Mapper will provide precise measures of the early clustering of matter in the reionization epoch. The Black Hole Mapper will map the innermost regions of accretion disks around supermassive black holes and image the X-ray shadow of their event horizons.



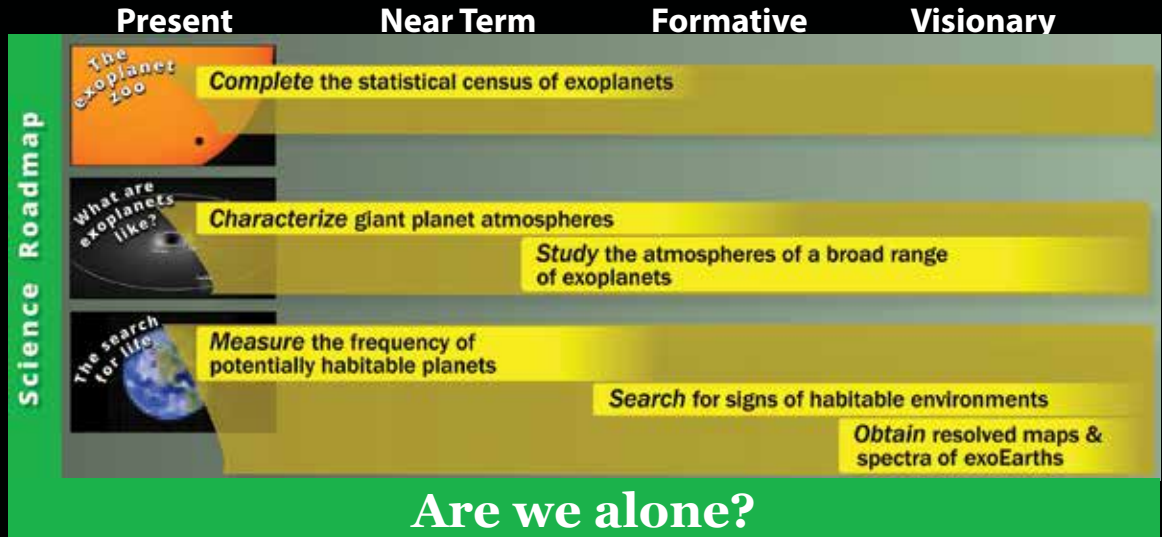
Formative Era (2020–2030)

- Far-IR Surveyor
- X-ray Surveyor
- Gravitational Wave Surveyor
- CMB Polarization Surveyor

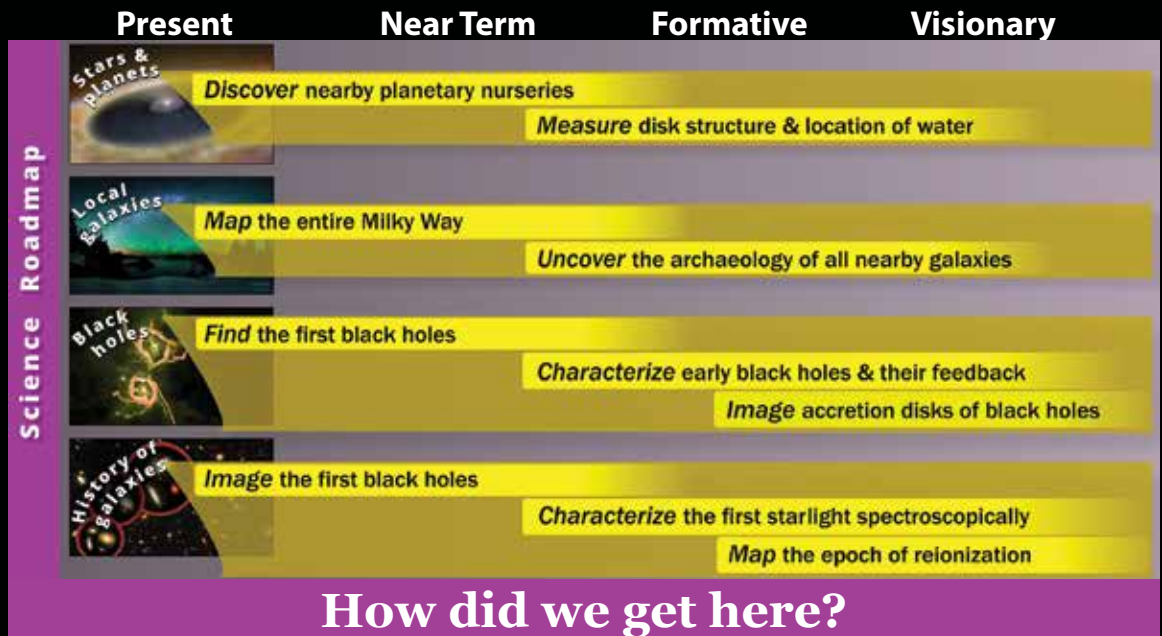
Visionary Era (2030+)

- X-ray Mapper
- Gravitational Wave Mapper
- Black Hole Mapper
- Cosmic Dawn Mapper

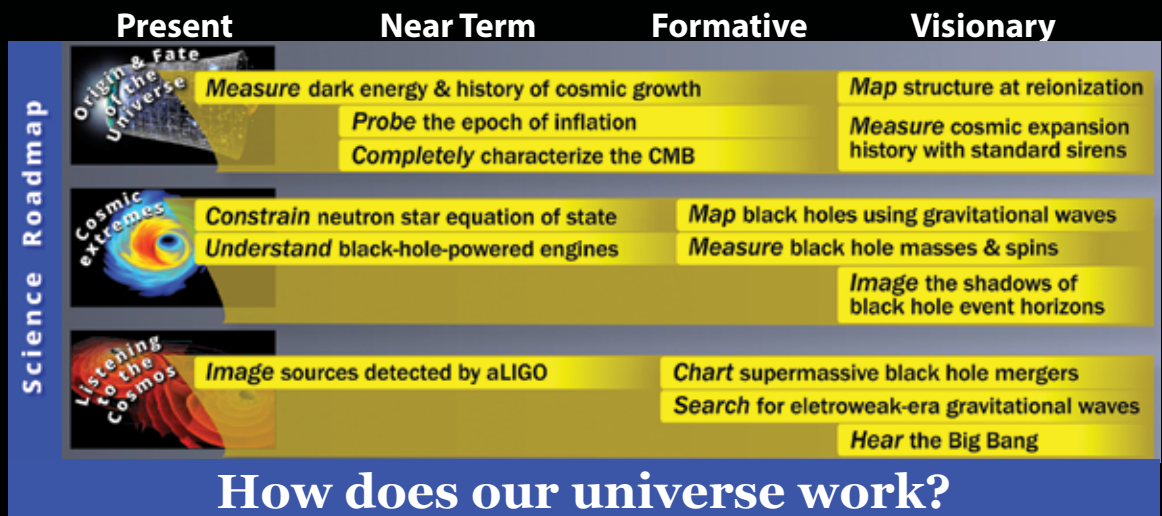
The Exoplanets Roadmap science themes include searching for signs of habitable worlds around other stars and obtaining resolved maps of the surfaces of these exoEarths.



The Cosmic Origins Roadmap includes science themes dealing with the transport of water in young planetary environments, mapping the merger history of all nearby galaxies, imaging the accretion disks around black holes, and probing the epoch of cosmic reionization.





The Physics of the Cosmos Roadmap science themes include measuring the universe's expansion history, direct detection of gravitational waves from the birth of the cosmos, and imaging the X-ray shadow of a black hole's event horizon.



Science Summary



	Formative Era					Visionary Era			
	GW Surveyor	CMB-pol Surveyor	FIR Surveyor	LUVOIR Surveyor	X-ray Surveyor	GW Mapper	Cosmic Dawn Mapper	ExoEarth Mapper	Black Hole Mapper
Demographics of planetary systems			Secondary	Primary				Secondary	
Characterizing other worlds			Secondary	Primary				Primary	
Our nearest neighbors and the search for life				Primary				Primary	
The origins of stars and planets			Primary	Primary				Primary	
The Milky Way and its neighbors	Secondary	Secondary	Primary	Primary	Primary	Secondary		Secondary	Primary
The history of galaxies	Primary		Primary	Primary	Primary		Primary	Secondary	Primary
The origin and fate of the universe	Secondary	Primary		Secondary	Secondary	Primary	Primary		
Extremes of matter and energy	Primary	Secondary			Primary	Primary			Primary
Ripples of space-time	Primary	Secondary				Primary			

 Primary Goals
  Secondary Goals

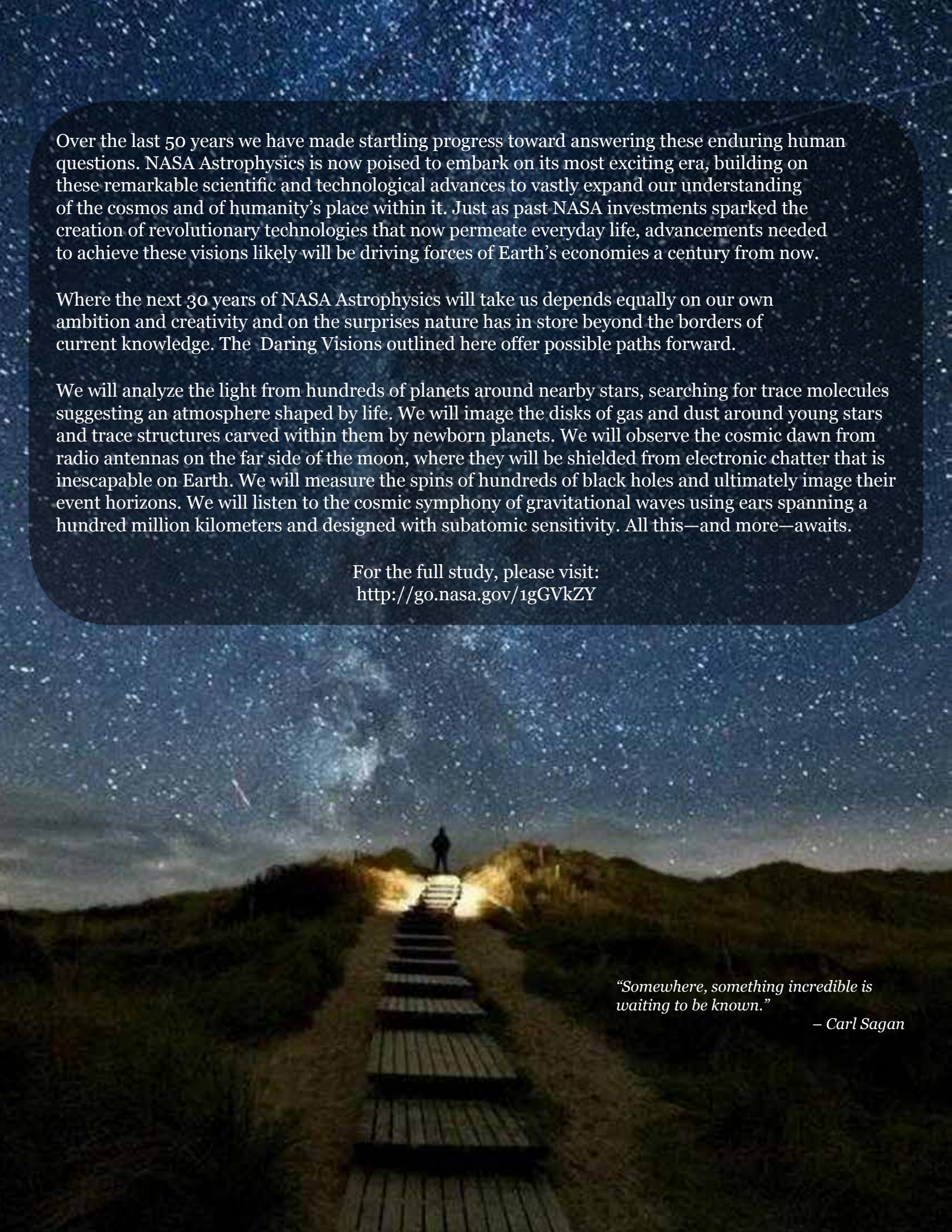
This chart shows the expected science return from a set of notional missions designed around the fundamental observational requirements for various parameters, such as wavelength, angular or spectral resolution, and sensitivity.

Technology Summary

	Formative Era					Visionary Era			
	GW Surveyor	CMB-pol Surveyor	FIR Surveyor	LUVOIR Surveyor	X-ray Surveyor	GW Mapper	Cosmic Dawn Mapper	ExoEarth Mapper	Black Hole Mapper
Formation flying				Beneficial		Essential		Essential	Essential
Interferometry: precision metrology	Essential		Beneficial			Essential	Essential	Essential	Essential
X-ray interferometry									Essential
High-contrast imaging techniques				Essential				Essential	
Optics deployment and assembly			Essential	Essential	Beneficial		Essential	Essential	
Broadband coatings		Essential		Essential					
X-ray optics					Essential				Essential
Large-format detector arrays		Essential	Essential	Essential	Essential				Essential
New detector capabilities			Essential	Beneficial	Essential				Essential
Cryogenics		Essential	Essential	Beneficial	Essential				

 Essential Goals
  Beneficial Goals

To achieve the goals of these notional missions, technology advances are needed in many key areas. This chart provides an overview of these enabling technologies.



Over the last 50 years we have made startling progress toward answering these enduring human questions. NASA Astrophysics is now poised to embark on its most exciting era, building on these remarkable scientific and technological advances to vastly expand our understanding of the cosmos and of humanity's place within it. Just as past NASA investments sparked the creation of revolutionary technologies that now permeate everyday life, advancements needed to achieve these visions likely will be driving forces of Earth's economies a century from now.

Where the next 30 years of NASA Astrophysics will take us depends equally on our own ambition and creativity and on the surprises nature has in store beyond the borders of current knowledge. The Daring Visions outlined here offer possible paths forward.

We will analyze the light from hundreds of planets around nearby stars, searching for trace molecules suggesting an atmosphere shaped by life. We will image the disks of gas and dust around young stars and trace structures carved within them by newborn planets. We will observe the cosmic dawn from radio antennas on the far side of the moon, where they will be shielded from electronic chatter that is inescapable on Earth. We will measure the spins of hundreds of black holes and ultimately image their event horizons. We will listen to the cosmic symphony of gravitational waves using ears spanning a hundred million kilometers and designed with subatomic sensitivity. All this—and more—awaits.

For the full study, please visit:
<http://go.nasa.gov/1gGVkZY>

"Somewhere, something incredible is waiting to be known."

– Carl Sagan