

Achieving the Goals and Objectives of the 2008 NASA Astrobiology Roadmap

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Introduction

The NASA Astrobiology Institute (NAI) formed the Planetary System Formation Focus Group (PSFFG) in 2008, in large part because of the unique opportunity presented by the Astronomy and Astrophysics 2010 Decadal Survey (Astro 2010) to provide advice about how the goals and objectives of the 2008 NASA Astrobiology Roadmap might be achieved in the coming decades. The NASA Astrobiology Roadmap is updated periodically, and the 2003 version was updated in 2007-08 and published in 2008 by D. J. Des Marais et al. (Astrobiology, Volume 8, Number 4, pages 715-730). The 2008 Roadmap was reviewed by the Executive Council of the NAI and by the Committee on the Origins and Evolution of Life of the National Academy of Sciences Space Studies Board. The 2008 Roadmap thus represents the most up-to-date, authoritative assessment of the goals and objectives of NASA's astrobiology initiative, and hence is a valuable guide for planning the federal government's investments in astronomy and astrophysics in the coming decades.

The purpose of this White Paper is to build directly upon the 2008 Roadmap by assessing to what extent various concepts for ongoing and proposed space- and ground-based telescopes address the Roadmap's goals and objectives. Because the science case for NASA's astrobiology efforts has already been developed in full in the published Roadmap, we will not attempt to reproduce that case here, but rather to highlight briefly the scientific rationale for the efforts of most relevance for the Astro 2010 survey. This White Paper will thus differ from many other White Papers submitted to Astro 2010, in that we have the advantage of the head start presented by the 2008 Roadmap.

Astrobiology Roadmap Goals and Objectives

Astrobiology seeks answers to three basic questions: How does life begin and evolve? Does life exist elsewhere in the universe? What is the future of life on Earth and beyond? In order to attempt to answer these three profound questions, the Roadmap lists seven Science Goals, each of which is likely to serve as an active area of research for several decades. Each Science Goal is accompanied by Science Objectives. It is intended that these Science Objectives should receive the highest priority for research in the near term. Because of the intrinsically multidisciplinary nature of astrobiology, involving molecular biology, ecology, planetary science, astronomy, and other disciplines, the Roadmap's Goals and Objectives span this same enormous breadth. Given that the Astro 2010 survey is limited to the missions envisioned for support by the Astrophysics Division of NASA's Science Mission Directorate, and not by, e.g., the Planetary Sciences Division, the following Goals and Objectives from the 2008 Astrobiology Roadmap (Des Marais et al. 2008) are the criteria by which this White Paper will assess the various missions.

Goal 1: Understand the nature and distribution of habitable environments in the universe. Determine the potential for habitable planets beyond the Solar System, and characterize those that are observable.

Objective 1.1: Formation and evolution of habitable planets.

Investigate how solid planets form, how they acquire liquid water and other volatile species and organic compounds, and how processes in planetary systems and galaxies affect their environments and their habitability. Use theoretical and observational studies of the formation and evolution of planetary systems and their habitable zones to predict where water-dependent life is likely to be found in such systems.

Objective 1.2: Indirect and direct astronomical observations of extrasolar habitable planets.

Conduct astronomical, theoretical, and laboratory spectroscopic investigations to support planning for and interpretation of data from missions designed to detect and characterize extrasolar planets.

Goal 3: Understand how life emerges from cosmic and planetary precursors. Perform observational, experimental, and theoretical investigations to understand the general physical and chemical principles underlying the origins of life.

Objective 3.1: Sources of prebiotic materials and catalysts.

Characterize the exogenous and endogenous sources of matter (organic and inorganic) ... in other planetary and protoplanetary systems.

Goal 7: Determine how to recognize signatures of life on other worlds... . Identify biosignatures that can reveal and characterize past or present life in ... remotely measured planetary atmospheres and surfaces. Identify biosignatures of distant technologies.

Objective 7.2: Biosignatures to be sought in nearby planetary systems.

Learn how to identify and measure biosignatures that can reveal the existence of life or technology through remote observations.

Extrasolar Planet Discoveries

Goals 1 and 7 of the 2008 Roadmap deal in large part with the desire to find evidence for life on extrasolar planets. Much of the current excitement in the field of extrasolar planets stems from the fact that well over 300 planetary systems in orbit around stars in our Milky Way galaxy have already been detected (see Figure 1), and the pace of discovery continues to accelerate. The planets detected to date range from exotic bodies unlike anything in our Solar System (e.g., the cinder-like planets in orbit around pulsars, the remnants of massive star evolution) to worlds that are more reassuringly familiar. In the latter category, we now have excellent evidence for the existence of gas giant planets, similar to Jupiter and Saturn, ice giant planets similar to Uranus and Neptune (i.e., the cold super-Earths found by microlensing), and hot and warm super-Earths that appear to be analogous to the terrestrial planets Mercury, Venus, Earth, and Mars. In fact, these hot and warm super-Earths appear to be incredibly commonplace, with some estimates being that such worlds are present around about 1/3 of all stars like the Sun (Mayor et al. 2009). One star, HD 40307 (see Figure 2), in fact appears to be orbited by not one or two, but by *three* super-Earths. These discoveries heighten the desire by worldwide astronomers to build space telescopes capable of detecting and characterizing Earth-like, inhabitable planets in the coming decades. Because of their high costs, these efforts will benefit from strong international collaborations between all interested space-faring nations.

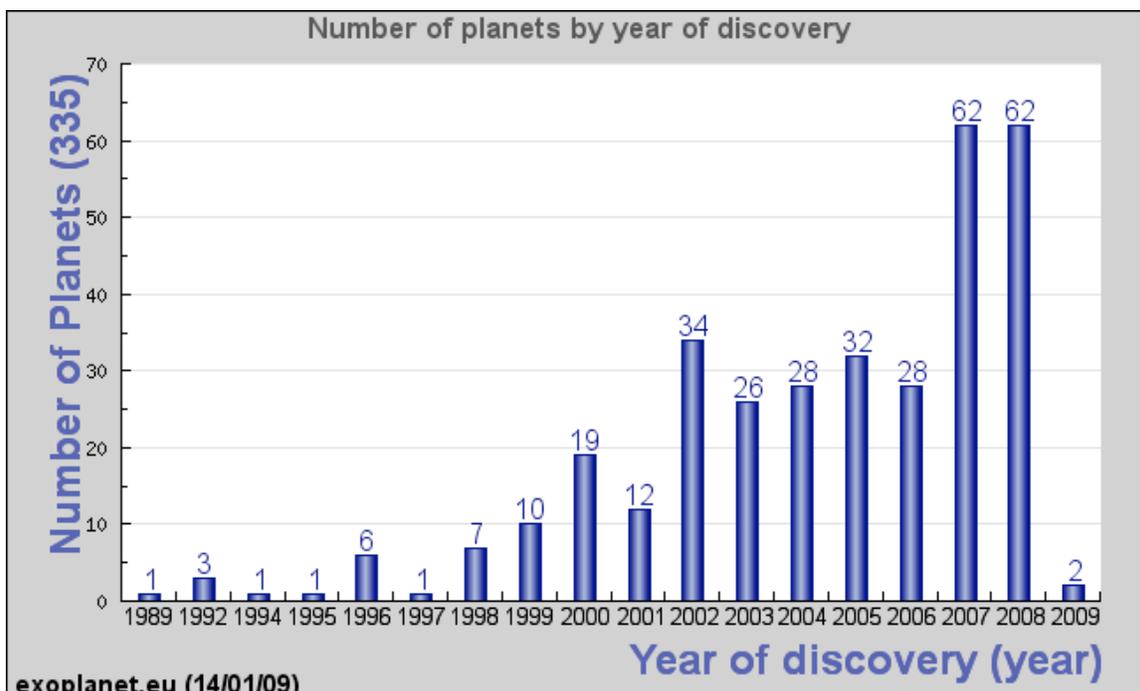
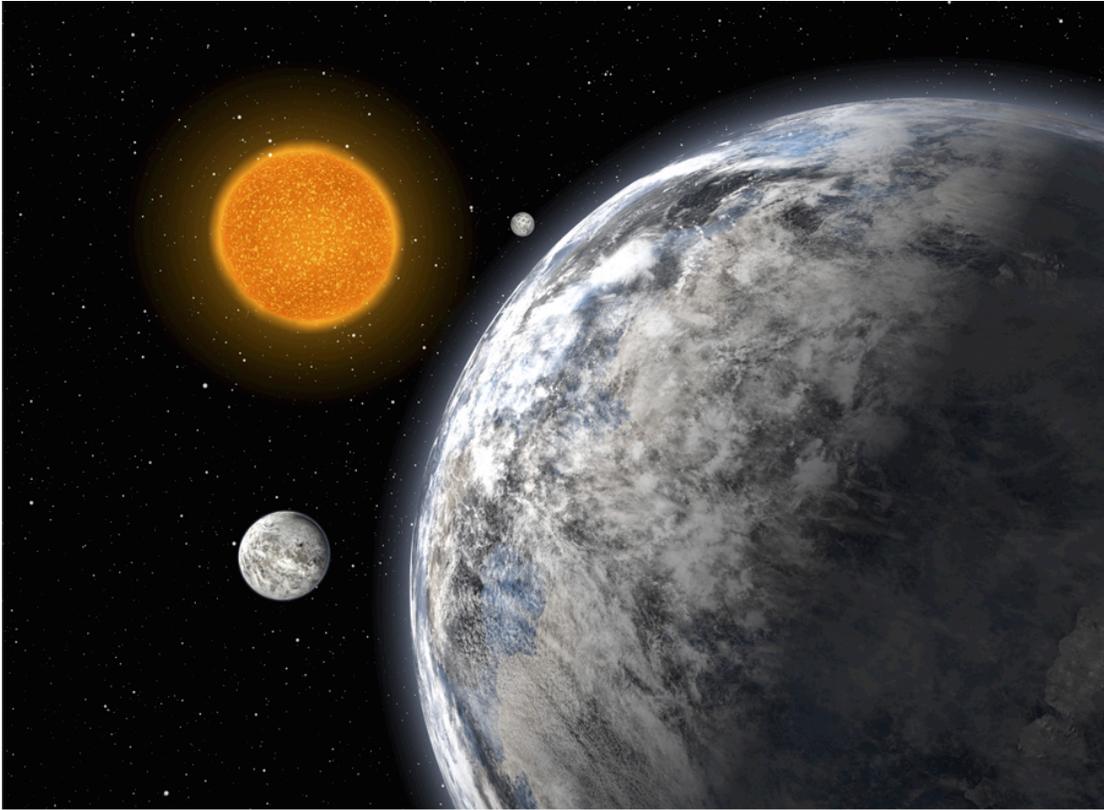


Figure 1. Number of extrasolar planets discovered per year. Histogram generated by Jean Schneider's Extrasolar Planets Encyclopedia web site (see <http://exoplanet.eu/>).



A Trio of Super-Earths (Artist's Impression)



ESO Press Photo 19a/08 (16 June 2008)

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Figure 2. Artist's impression of the trio of super-Earths discovered by an European team headed by Michel Mayor (Geneva Observatory) using the HARPS spectrograph on ESO's 3.6-m telescope at La Silla, Chile, after 5 years of monitoring. The three planets, having 4.2, 6.7, and 9.4 times the mass of the Earth, orbit the star HD 40307 with periods of 4.3, 9.6, and 20.4 days, respectively. (Image courtesy of the European Southern Observatory, ESO. From M. Mayor et al. 2009, *Astronomy & Astrophysics*, volume 493, p. 639.)

Planetary Science Formation Focus Group Meeting

In order to better assess the opportunities presented by the various space- and ground-based telescopes to be considered by Astro 2010, the PSFFG held an all-day meeting on January 7, 2009, in conjunction with the American Astronomical Society (AAS) meeting in Long Beach, California. The meeting consisted of invited presentations by representatives of most of the space- and ground-based telescopes thought to be of relevance to the astronomical aspects of the 2008 Roadmap. Approximately 100 different astronomers attended the meeting at some time during the day.

NAI PSFFG LONG BEACH MEETING AGENDA

Current Missions:

Warm SST -- Michael Werner (JPL)
HST post-SM4 -- Christine Chen (STScI)
Kepler -- David Koch (NASA Ames)
Herschel -- Hal Yorke (JPL)
JWST -- Mark Clampin (NASA GSFC)
SOFIA -- Eric Becklin (UCLA)

Proposed Space Missions:

SIM Lite -- Mike Shao (JPL)
Terrestrial Planet Finder - C -- Wes Traub (JPL)
Terrestrial Planet Finder - I -- Chas Beichman (Caltech)

Space Strategic Mission Concepts:

ASPIRE -- Scott Sandford (NASA Ames)
THEIA -- David Spergel (Princeton U.)
ATLAST -- Marc Postman (STScI)
EPIC -- Mark Clampin (NASA GSFC)
NWO -- Webster Cash (U. Colorado)
DAVINCI -- Mike Shao (JPL)
PECO -- Olivier Guyon (U. Arizona)
ACCESS -- John Trauger (JPL)

Ground-based Telescopes:

GSMT -- Michael Meyer (U. Arizona)
ALMA -- Alwyn Wootten (NRAO)

Small Explorer Mission:

TESS -- George Ricker (MIT)

Each presenter was asked to evaluate how their mission would be able to address the Roadmap goals listed above. Copies of their presentations were collected and used to perform the assessments detailed in this White Paper. Considering that Roger Blandford, chair of Astro 2010, stated in his Town Hall talk to the AAS on January 6 that JWST and SOFIA would *not* be subject to prioritization in the Astro 2010 survey, this White Paper will not assess these two missions, in spite of the presentations given on their behalf at the PSFFG meeting.

Assessments of Value of Specific Missions to Astrobiology Roadmap

We will not attempt to summarize the specific measurement capabilities proposed for the various missions, their risks with regard to technical difficulty, cost, and schedule, or any of the other major factors that will help to determine in the end the prioritization of missions that is the ultimate product of the Astro 2010 survey. Rather, we will simply accept as fact what the missions are claiming to be able to accomplish, without trying to assess whether or not these claims are in fact realizable. The Programmatic Prioritization Panels of Astro 2010 will perform this latter analysis. Here we are content to assign a symbolic grade to each mission with respect to the extent to which its objectives will be able to make a significant contribution to the Goals and Objectives of the 2008 Roadmap.

Missions	Assessments of Value to 2008 Roadmap		
	Goal 1	Goal 3	Goal 7
Current Missions:			
Warm SST	+	--	--
HST post-SM4	+	+	+
Kepler	*	--	--
Herschel	--	+	--
Proposed Space Missions:			
SIM Lite	*	--	--
Terrestrial Planet Finder - C	*	--	*
Terrestrial Planet Finder - I	*	*	*
Space Strategic Mission Concepts:			
ASPIRE	--	*	+
THEIA	*	--	*
ATLAST	*	--	*
EPIC	+	--	+
NWO	*	+	*
DAVINCI	*	--	*
PECO	+	--	+
ACCESS	+	--	+
Ground-based Telescopes:			
GSMT	+	+	+
ALMA	+	+	+
Small Explorer Mission:			
TESS	+	--	--

The assessments are given as symbols as follows:

- * = highly valuable
- + = valuable
- -- = not relevant for this goal.