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New Worlds, New Horizons and NASA's approach to the next decade of exoplanet discoveries

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Abstract. Every ten years the astronomy and astrophysics community in the United States undertakes a survey intended to prioritize plans for major ground- and space-based astronomical facilities for the coming decade. *New Worlds, New Horizons* (NWNH) was released in August 2010 and represents the community's advice to the United States' funding agencies about the top priorities for 2010-2020. Here we focus on the recommendations of NWNH for space-based exoplanet missions to be considered by NASA, and on the plans developed to date for how NASA will respond to the science goals and missions set out for them by NWNH.

Keywords. planetary systems, astrometry, space vehicles, instrumentation: high angular resolution, techniques: interferometric, photometric, radial velocities, spectroscopic

1. Introduction

Beginning in 1964 with the Whitford Report, astronomers and astrophysicists in the United States have prepared detailed reports that prioritize their preferences for major ground- and space-based astronomical facilities for the coming decade. The most recent of these Decadal Survey reports, entitled *New Worlds, New Horizons* (NWNH) was released in August 2010. The chair of this Decadal Survey Committee was Roger Blandford, and as a result NWNH will undoubtedly be known as the Blandford Report in the future (Blandford *et al.* 2010). The other Decadal Surveys issued in the interval between 1964 and 2010 were the Greenstein Report (1972), the Field Report (1982), the Bahcall Report (1991), and the McKee-Taylor Report (2001), all named after their respective chairpersons.

NWNH represents the astronomical community's attempt to speak with a single voice to three of the United States' science funding agencies regarding the top astronomical priorities for 2010-2020: the National Aeronautics and Space Agency (NASA), the National Science Foundation (NSF), and the Department of Energy (DOE). While NASA focuses almost entirely on space-based missions, and NSF on ground-based telescopes, DOE has expressed an interest in both ground- and space-based efforts to understand dark energy. In this brief summary, we focus on the recommendations of NWNH for future space-based exoplanet missions to be considered by NASA, and on the plans developed to date by NASA Headquarters and by NASA's Exoplanet Exploration Program to address these top priority goals.

2. NWNH Decadal Survey

NWNH differed in several important respects compared to the five previous Decadal Surveys. First, determination of the top science goals was performed by a set of Science Frontier Panels covering the major disciplines of astronomy and astrophysics, while a separate set of Program Prioritization Panels considered the wide variety of projects proposed for the next decade and beyond. In the past, both tasks were performed by the same panels. Second, projects that had previously been approved for development by past Decadal Surveys were to be reconsidered anew, unless they were already well underway (e.g., the James Webb Space Telescope – JWST – which was recommended by the McKee-Taylor Report). The Space Interferometry Mission (SIM), intended to detect and determine the masses of Earth-like planets orbiting the closest solar-type stars, first recommended in the 1991 Report, and then recommended again in the 2001 Report, was thus tossed back into the fray in the 2010 Report. Third, all major projects would be subjected to an independent assessment of their cost estimates, in the case of the space-based missions performed by an aerospace corporation with extensive experience in space satellites. Finally, the recommended program had to be consistent with the actual funds expected to become available for new starts in the 2010-2020 decade.

The Blandford Report recommended a number of small, medium, and large projects for deployment both on the ground and in space in 2010-2020. In the context of this particular IAU Symposium, which links exoplanet scientists from around the world, it is also noteworthy that NWNH specifically took note of the increasingly collaborative, international, and interdisciplinary nature of contemporary astronomy, and recommended that the US science funding agencies should consider US participation in international projects, in order to permit access to these new facilities by US scientists, and to maximize the scientific output from the world's major astronomical facilities. Given the fact that the US Decadal Surveys are somewhat out of step with other planning efforts, such as the Cosmic Visions process currently underway in Europe, NWNH recommended that the international astronomical community should meet roughly every five years to share their strategic plans and consider opportunities for collaboration on the largest projects.

In the area of large space-based projects, i.e., those costing over $1B, NWNH ranked the Wide Field InfraRed Survey Telescope (WFIRST) as the top priority, followed by an augmentation to NASA's Explorer Program, the Laser Interferometer Space Antenna (LISA), and the International X-ray Observatory (IXO). WFIRST is intended to be a 1.5-m space infrared telescope with three main science goals, all of equal priority: a search for exoplanets by gravitational microlensing, galactic and extragalactic surveys, and dark energy. The Explorer Program supports the development of relatively low cost (less than $300 million US) space telescopes proposed by US astronomers. LISA would be a joint effort with the European Space Agency (ESA), intended to detect gravitational waves. IXO, also a joint international effort, would be a successor to NASA's current X-ray observatory, Chandra. SIM had been proposed to the 2010 Decadal Survey as a reduced cost mission, dubbed SIM-Lite, yet even with this major concession failed to make the final top priorities of NWNH.

WFIRST was envisioned by NWNH to cost $1.6B, with only a moderate level of risk of meeting its science goals, and to be started in 2013 with the goal of launching in 2020. WFIRST would be coupled with NWNH's top priority for large ground-based projects, the Large Synoptic Survey Telescope (LSST), to be built with the support of NSF and DOE. WFIRST and LSST are interlinked in the area of dark energy studies, where optical

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observations would be made from the ground by LSST and the corresponding infrared observations would be done by WFIRST.

NWNH noted that ESA is currently considering another space-based dark energy mission, Euclid, which is competing as a part of the current Cosmic Visions process for possible launch in 2017-2018. While Euclid focuses on dark energy, exoplanet surveys by gravitational microlensing are possible as a secondary science objective. NWNH thus stated that a collaborative effort between NASA and ESA might be a possibility, provided that a joint mission addresses all three of NWNH's science goals for WFIRST, makes sense economically, and that the US plays "a leading role in this top-priority mission".

It is interesting to note that NWNH ranked LSST above the Giant Segmented Mirror Telescope (GSMT), a 25- to 30-m ground-based telescope that would be valuable for a variety of exoplanet studies. GSMT had been proposed as the top ground-based major initiative in the 2001 McKee-Taylor Report, but had also been forced to compete again in the 2010 Decadal Survey, where it dropped down a notch in the final prioritized list. LSST moved up several notches in NWNH from its ranking in the 2001 Report. The Terrestrial Planet Finder (TPF), the third-ranked large space mission in the McKee-Taylor Report, disappeared altogether in NWNH, with the possible exception of inclusion in a technology development effort.

NWNH recommended that NASA begin a medium-scale technology development program directed toward the discovery of exoplanets. The New Worlds Technology Development Program is intended to help achieve the objective of discovering and characterizing nearby habitable exoplanets. Before deciding upon a specific concept for a flagship-class mission like TPF, NWNH suggested that the frequency of Earth-like planets be determined first, by a combination of NASA's Kepler Mission (now underway), WFIRST, and ongoing ground-based search programs with a variety of techniques. Further measurements of the level of exozodiacal dust emission and reflection around likely target stars also need to be achieved, as such emission and reflection can stymie direct detection efforts at both optical and infrared wavelengths. A combination of ground-based, sub-orbital, and Explorer-class telescopes was proposed by NWNH to address the exozodiacal light issue. NWNH then recommended that these efforts could lead to an informed choice about the design of a flagship mission between 2015 and 2020. Given that NWNH suggested a 2020 launch date for WFIRST, it is unlikely that WFIRST will inform such a decision, though this role for WFIRST will be obviated by the success of Kepler, whose primary science goal is to determine the frequency of Earth-like planets, which will be accomplished by 2013. NWNH recommended spending between \$100 million and \$200 million US on this effort over the decade.

While NWNH's top priorities were planned to fit into the expected NASA budget profile for new missions in 2010-2020 that was estimated in the summer of 2009 when the Decadal Survey was well underway, a severe decrease in the total amount of such funds from roughly \$4B to \$2B in the intervening time period has presented NASA with a major challenge in implementing the NWNH recommendations. NWNH recommended that if NASA's funds were reduced, the top priorities for space should be WFIRST and the Explorer Program augmentation, followed by the New Worlds Technology Development Program, and LISA and IXO Technology Development.

We now turn to a summary of the plans currently envisioned by NASA Headquarters and by the Jet Propulsion Laboratory (JPL), the lead NASA center for the Exoplanet Exploration Program.

3. NASA's Approach to the Next Decade of Exoplanet Discoveries

3.1. *The NWNH Framework for Exoplanet Exploration*

The discussion and recommendations presented in NWNH are arranged according under three broad scientific categories. The first, Cosmic Dawn, is focused on understanding the evolution of the early universe, and the processes that led to the formation of the first stars and galaxies. The second, Physics of the Universe, seeks to exploit the universe as a grand laboratory to deepen our understanding of fundamental physical laws and principles. The third, New Worlds, addresses the quest to search out and characterize extrasolar planets. Not surprisingly, it is the priorities and recommendations that pertain to the New Worlds science theme that will have the most direct impact on NASA's Exoplanet Exploration Program (ExEP) in the coming years.

Within the New Worlds science theme, NWNH articulates three key science objectives for the coming decade. The first is to complete the statistical census of exoplanetary system architectures and develop an unbiased determination of the abundance of rocky, Earth-sized planets on large orbits. Noting that the two techniques responsible for the majority of exoplanet discoveries to date (radial velocity (RV) measurements and transit detections) are strongly biased are toward large planets on small orbits, NWNH advocates an additional, complementary exoplanet detection technique: gravitational microlensing. Gravitational microlensing is a phenomenon wherein the light that we receive from a distant background star is temporarily magnified by the gravitational field of an intervening star as its relative motion carries it in front of the background star. If the intervening star has a planet in orbit around it, the planet can produce detectable substructure in the observed brightness variation. Gravitational microlensing is a very sensitive technique, capable of revealing even sub-Earth-mass exoplanets. More importantly, however, the technique is biased toward the detection of planets on large (1 AU) orbits. Consequently, a microlensing exoplanet census would in some sense mitigate the bias inherent in RV/transit surveys and provide scientists with a more complete picture of exoplanetary system architectures.

The second New Worlds science objective articulated by NWNH is the need to conduct a survey of Earth-mass planets in the habitable zones of stars in the solar neighborhood. Such a survey is desirable because it will provide a target list of promising candidates for a future exoplanet mission capable of direct imaging and spectroscopy of potentially habitable worlds.

Finally, the third New Worlds science objective is the characterization of the exozodiacal dust clouds in exoplanetary systems. Dust in exoplanetary disks will have an important impact on the detectability of planets in those systems. Thus, understanding the amount and distribution of that dust is an important precursor to the design of a future direct detection mission.

In order to achieve the foregoing New Worlds science objectives, and to advance the field of exoplanet exploration in the coming decade, NWNH offers a series of implementation recommendations. These include:

1. Perform a space-based microlensing survey to characterize in detail the statistical properties of habitable terrestrial planets. This is one of the three primary science objectives of the Wide Field Infrared Survey Telescope (WFIRST), the highest priority Large space mission recommended by NWNH.

2. Improve RV measurements on existing ground-based telescopes to locate the prime targets for hosting habitable, terrestrial planets among our closest stellar neighbors and to discover planets as small as 2-3 $M_{\oplus}$ as targets for future spacebased direct detection missions.

3. Use ground-based telescopes or a space-based Explorer mission, to characterize the dust environment around stars like the Sun, so as to gauge the ability of future missions to directly detect Earth-size planets on orbits like that of our own Earth.

4. Develop the technology for a future space mission to study nearby Earth-like planets. The goal of this program, the New Worlds Technology Development Program, is to lay the ground work for a planet-imaging and spectroscopy mission beyond 2020, including precursor science activities. The New Worlds Technology Development Program is the highest priority Medium space project recommended by NWNH.

5. Use JWST to characterize the atmospheric and/or surface composition of planets down to super-Earth masses orbiting the coolest red stars.

6. Carry out a focused program of computation and theory to understand the architectures of planets and disks.

Although the process of developing a program plan to address the recommendations of NWNH is in its very earliest stages, the following sections will summarize some of the plans and activities that are already in place.

3.2. *NWNH Recommendation L-1: The Wide-Field Infrared Survey Telescope*

The highest-priority, Large space mission recommended by NWNH is the Wide-Field Infrared Survey Telescope, or WFIRST. WFIRST is a mission concept for a near-IR space observatory that will conduct wide-field imaging and low-resolution spectroscopy from a vantage point at L2 over a five-year mission lifetime. WFIRST's design will be optimized to support a three-pronged science mission combining Dark Energy science, a microlensing exoplanet census, and other galactic and extragalactic large-area surveys, including a guest observer program. It is worth noting that NWNH emphasized that all three components of the WFIRST science program are of equal importance, and the loss of any one of them would significantly reduce the value of the mission in the eyes of the Decadal Survey Panel.

In the near term, NASA plans to initiate several pre-formulation activities that will begin to lay the foundation for WFIRST. First, NASA has already issued a call for proposals for scientists interested in participating in the WFIRST Science Definition Team (SDT) and plans to announce selections in early 2011. The SDT will include scientists whose specialization spans the complete range of all recommended mission science programs, and will be tasked with articulating the science goals of the mission, and developing an optimized implementation plan. In addition, NASA will also begin technical/engineering support for development of the WFIRST mission concept as resources allow, and will support relevant technology development through its existing programs. Finally, NASA will begin to explore the possibility of interagency and/or international participation in WFIRST, participation which may include representation on the SDT. Beyond these early activities, further development of WFIRST will be influenced by several important budgetary and scientific considerations. On the financial side, NASA's ability to implement WFIRST will be determined almost entirely by the budget profile and schedule for JWST. This is true not only because of the large cost associated with implementing any flagship space mission, but also because NASA's Astrophysics budget is projected to remain essentially flat at ca. $1B through the middle of the coming decade (the current budget horizon). Thus, there will be little funding available to undertake the start of a major new mission until JWST development is complete, and that portion of the budget can be directed to development of the next mission. The science environment in the coming decade will also influence the implementation of WFIRST. This environment will be shaped by such factors as: (a) development of the Large Synoptic Survey Telescope (LSST; NWNH's top-priority, Large ground-based project) and other

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ground-based facilities by the NSF and the U.S. Department of Energy; (b) ongoing and future investigations by Hubble, Chandra, Spitzer, JWST, etc.; (c) scientific results from future potential Explorer missions; and, (d) missions under development by other nations (e.g., Euclid, PLATO). Consequently, it is likely to be several years before the details of the path that NASA will follow over the coming decade to implement WFIRST will become clear.

3.3. *NWNH Recommendation L-2: Augmentation to NASA's Explorers Program*

The second Large space project recommendation of NWNH is a significant augmentation to the budget for NASA's Explorer Program. The Explorer Program supports competed, PI-led space missions that fall into three categories: (1) Medium-class Explorers (MIDEX), which are cost-capped at ca. $300M; (2) Small Explorers (SMEX), which are cost-capped at ca. $160M; and, (3) Missions of Opportunity (MoO), which are typically $35M. Over the years, Explorer missions have delivered a high level of scientific return on relatively moderate investments, and have provided the capability to respond rapidly to new scientific and technical breakthroughs. Recognizing the proven value of the Explorers Program, NWNH recommended a budget augmentation to the program sufficient to support two Astrophysics MIDEX missions, two Astrophysics SMEX missions, and four Astrophysics MoOs in the coming decade. This represents a doubling of the planned flight rate for the program. As this is a competitive program, there is no guarantee that any exoplanet exploration missions will be selected to fly in the coming decade. However, given the inherently compelling nature of the science, its prominence in NWNH, and the number of highly-competitive, Explorer-class exoplanet mission concepts, prospects for such a mission would appear to be bright.

3.4. *NWNH Recommendation M-1: New Worlds Technology Development*

Few scientific endeavors are as compelling to scientist and non-scientist alike as the search for other habitable, Earth-like worlds. Indeed, it is for just that reason that the New Worlds science theme plays such a prominent role in NWNH. However, simply detecting the presence of habitable, Earth-sized planets around other stars pushes the very limits of current technology; actually isolating the light from such a planet from the overwhelming glare of its parent star so that it can be imaged and its spectrum measured will require significant technological advancements in a number of different areas. Moreover, the optimal architecture by which the necessary degree of starlight-suppression can be achieved is yet unclear. Coronagraphy, external occultation, and interferometry have all been given significant consideration in this regard, and each has its own set of advantages, disadvantages, and challenges. In view of the tremendous challenges yet to be overcome and the tight budgetary constraints it was forced to work within, NWNH concluded that it would not be feasible to execute a direct-detection mission in the coming decade. On the other hand, acknowledging the paradigm-shifting nature of such an endeavor, NWNH recommended a significantly increased investment in exoplanet technology development in the form of its New Worlds Technology Development Program. The goal of that program is to lay the technical and scientific foundations for a space mission capable of imaging and spectroscopy of habitable, rocky planets in the 2020 decade. The importance of this effort within the framework of NWNH is reflected in its placement as the top-priority, Medium class project. The New Worlds Technology Development Program envisioned by NWNH would be implemented through a two-stage process. The first stage calls for stepped-up funding for exoplanet technology development activities spanning all of the candidate starlight suppression techniques (coronagraphy, interferometry, star-shades) through mid-decade. If, at that point, the scientific groundwork

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and design requirements for a direct-detection mission are sufficiently clear, a technology down-select should be made. Subsequent investments in the latter half of the decade (the second stage of the program) should be increased dramatically and focused on advancing the most promising mission architecture. The goal of the New Worlds Technology Development Program is to develop a mature concept for a flagship mission to conduct imaging and spectroscopy of habitable, terrestrial exoplanets for consideration by the 2020 Decadal Survey. Fortuitously, NASA's existing Astrophysics Strategic Research and Technology (SR&T) portfolio is well-suited to implementing the substance of the New Worlds Technology Development Program. In the current portfolio, exoplanet technology development is funded primarily through two programs:

(a) Astrophysics Research and Analysis (APRA). The APRA program supports (among other things) fundamental research into new exoplanet technologies, i.e. Technology Readiness Levels (TRL) 1-3.

(b) Technology Development for Exoplanet Missions (TDEM). TDEM is a component of NASA's Strategic Astrophysics Technology (SAT) program. It supports the mid-range maturation of exoplanet technologies whose feasibility has already been demonstrated, i.e., TRL 3-6.

It should be noted that mission-enabling, ground-based precursor science activities are included in the scope of TDEM. However, in this context, the term mission-enabling science is carefully defined as science that advances technologies or informs the design of future NASA flight missions. Thus, investigations such as high-precision RV surveys of planetary systems in the solar neighborhood, or characterization of exozodiacal dust disks, would fall within the purview of the program if suitably motivated.

4. Other Exoplanet Exploration Activities in the Coming Decade

4.1. *NWNH Small Initiatives*

Several of the (unprioritized) Small Initiatives recommended by NWNH are also likely to contribute to NASA's Exoplanet Exploration activities in the coming decade. These include:

(a) an augmentation to NASA's Astrophysics Theory Program (ATP) which supports research into the origin and evolution of exoplanetary systems;

(b) an augmentation to NASA's Suborbital Program to increase flight rate, which would create additional opportunities for suborbital exoplanet investigations; and,

(c) definition of a future UV/optical space observatory that could reasonably include exoplanet exploration as a component of its science mission.

4.2. *Ongoing Activities*

Outside of the recommendations of NWNH, NASA is engaged in a number of ongoing exoplanet exploration activities that will likely make important contributions to the field in the coming years. First and foremost is the Kepler mission. At the time of this writing, Kepler has completed about one and a half of its three and a half year prime mission, and the Kepler Science Team is engaged in the prodigious task of analyzing the data and following up on potential exoplanet detections. In addition, the first two quarters of mission data are now available in the public domain and analyses based on those data are eligible for funding under NASA's Astrophysics Data Analysis Program (ADAP). Thus, the number of exoplanets discovered by Kepler will undoubtedly increase dramatically over the next few years, and the mission should yield our first direct measurement of the

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frequency of Earth-sized planets by the middle of the coming decade. On the ground, NASA continues to support exoplanet exploration investigations at both the W.M. Keck Observatory in Hawaii and the Large Binocular Telescope in Arizona. At Keck, NASA supports high-resolution radial velocity observations with the HIRES instrument for both Kepler follow-up and general exoplanet observations. It should be emphasized that, although a portion of NASA's Keck time is set aside for Kepler follow-up observations by the Kepler Science Team, proposals for Kepler follow-up observations from the wider scientific community in response to NASA's biannual Keck solicitations are welcome and encouraged. NASA support for the Keck interferometer has also been extended into 2012, and options for future support of that facility are currently being discussed with the NSF.

In Arizona, the Large Binocular Telescope is nearing completion, and initial testing of the NASA-funded Large Binocular Telescope Interferometer (LBTI) is already underway. The key science project for the LBTI will be to explore the exozodiacal dust environments of nearby stars at mid-infrared wavelengths, directly addressing one of the New Worlds science objectives articulated in NWNH. In addition to this key science program, once the LBTI is fully operational, NASA plans to make time on this facility available to the scientific community for exoplanet-related and other science investigations on a competitive basis.

Finally, NASA will continue to support fundamental exoplanet research through a suite of competitively selected R&A programs including the previously-mentioned ADAP and ATP programs, as well as other programs such as Origins of Solar Systems and Planetary Atmospheres.

4.3. *Programmatic Impacts of NWNH*

In any prioritization process, some opportunities must be sacrificed so that others can proceed. In this final section, we will examine two prominent exoplanet exploration activities that must be abandoned in deference to the NWNH recommendations.

4.4. *Space Interferometry Mission (SIM-Lite)*

After careful consideration, the Decadal Survey panel made the difficult decision not to include the SIM-Lite mission among its priorities for the coming decade. This decision was driven primarily by two factors. First, the panel concluded that the $1.9B price tag obtained through its own independent cost estimate and the projected 8.5 yr time-to-launch made SIM-Lite uncompetitive in the rapidly changing field of exoplanet science. In addition, the panel found that rapid advances in ground-based observational capabilities had eroded SIM-Lite's importance as a target-finding mission for a future direct-detection mission. Specifically, the panel concluded, the role of target-finding for future direct-detection missions, one not universally accepted as essential, can be done at least partially by pushing ground-based radial-velocity capabilities to a challenging but achievable precision below 10 centimeters per second. As a consequence, NASA's Science Mission Directorate has formally discontinued sponsorship of the SIM-Lite project and directed the project to initiate shut-down activities. Closeout activities will include retention of all SIM hardware by NASA's Exoplanet Exploration Program for potential future use, archiving of all SIM-related technology and design documentation, and reassignment of personnel to new work. Termination activities should be completed by the end of 2010.

4.5. *Participation in ESA's PLATO Mission*

Prior to the release of NWNH, the European Space Agency invited NASA to consider a 20% partnership on two of its Cosmic Visions M-Class mission candidates: the PLAnetary Transits and Occulations of stars (PLATO) mission and the Euclid mission to map the geometry of the dark universe. These opportunities were described in a letter from NASA to the Decadal Survey panel in early April 2010. Subsequent to this invitation, NASA supported the participation of US scientists and engineering teams in ESA's planning and optimization studies for each concept during May/June 2010. However, throughout these activities, NASA emphasized that its participation in either or both of these missions would be contingent upon the recommendations of NWNH.

As discussed above, NWNH emphasized the importance of completing the census of exoplanetary systems with a technique that mitigated the bias inherent in the transit technique, as well as the need to conduct a survey of nearby habitable, Earth-sized planets and determine the exozodiacal dust characteristics of those systems. The PLATO mission does not address either the first or the last of these science objectives. Moreover, the observing strategy currently planned for the PLATO mission (a combination of two long-duration pointings lasting three- and two-years, respectively, followed by a series of shorter pointings of a few months each) is not well suited to the detection of habitable, rocky planets around stars other than late-type dwarfs. Consequently, NASA has concluded that the scientific objectives of the PLATO mission are poorly aligned with the recommendations of NWNH, and has notified ESA that it does not intend to pursue a strategic partnership in the mission, even if it is ultimately selected for flight through the Cosmic Visions process.

5. NASA's Exoplanet Exploration Program

The messages in NWNH from the astronomical community to those of us in its exoplanet subset are quite clear: exoplanet science is an exciting field, exoplanet science deserves a major portion of the WFIRST mission in this decade, and exoplanet science is currently earmarked for a dedicated space mission in the following decade.

The path to a dedicated mission in the 2020s has even been mapped out for us by NWNH: community agreement on a "*mission definition for a space-based planet imaging and spectroscopy mission*" by mid-decade (i.e., 2015), a "*technology down-select*" around that same time, and an augmented "*mission-specific technology program starting mid-decade*" in preparation for "*a mission start in the 2020 decade*". (All quotes in this section are directly from the NWNH report, specifically pages 7-22 and 7-23, italics added.)

NWNH says "*Detecting signatures of biotic activity is within reach in the next 20 years if we lay the foundations this decade for a dedicated space mission in the next.*" The report continues with more specific directions: "*For the direct detection mission itself, candidate starlight suppression techniques (for example, interferometry, coronagraphy, or star shades) should be developed to a level such that mission definition for a space-based planet imaging and spectroscopy mission could start late in the decade in preparation for a mission start early in the 2020 decade.*"

The funding profile for achieving this is hinted at in NWNH, where a low profile for the first half of the decade is suggested, ramping up to a much higher level in the second half. The message here is that we should not expect funding to be much different in the coming 5 years than it has been in the past few years. This is a disappointment to many researchers. However we can also read this as saying that the authors of NWNH feel that we already have in hand a sufficient number of good ideas for imaging and spectroscopy, and that all we have to do is to refine these somewhat, and internally select what we believe is the most promising of the pack.

The NWNH report is not specific on the down-select mechanism, saying only that "*If the scientific groundwork has been laid and the design requirements for an imaging mission have become clear by the second half of this decade, a technology down-select should be made ...*". The report does not say that this should be a formal down-select directed by NASA, although that could be an option.

The exoplanet community might be wise to heed the example of related communities (e.g., far-infrared, x-ray, Mars) by doing the down-select internally, and agreeing to agree on the result, as with the NWNH process itself. By agreeing on a mission, and presenting a united front to the world, we are much more likely to succeed.

To do the opposite, to disagree until the bitter end, and expect a mystical authority figure to make the decision between warring tribes, is to invite disaster.

The obvious and appropriate venue for making a community down-select decision is the Exoplanet Program Analysis Group (ExoPAG). The ExoPAG was created to provide scientific analysis on exoplanet topics to NASA headquarters and to the Exoplanet Exploration Program (ExEP), via the Astrophysics Subcommittee, which is in turn a part of the NASA Advisory Council. Thus the ExoPAG is the single community entity officially designated to provide analysis information on exoplanet matters in the US.

Technically, the ExoPAG membership is the entire exoplanet community. The ExoPAG Executive Council is a 10-member group with a rotating membership, drawn from among volunteer scientists. However since the ExoPAG itself constitutes the entire community, it is expected that there should be wide participation by all interested parties, through the mechanism of ExoPAG meetings (typically along with winter and summer AAS meetings) and through telecons set up for topic-specific discussions.

The ExoPAG chair, James Kasting, has suggested the following tentative schedule for working toward a community down-select by 2015: (a) formulate study groups and assign tasks, by mid-2011; (b) report on exoplanet science goals and instrumentation options for a mission in the 2020s, by mid-2012; (c) report on mission technology, engineering, and verification challenges, mid-2013; (d) present a detailed design reference mission (DRM) for that mission, early 2014. The detailed schedule may change, but the intent will remain, to produce a community down-select by mid-decade.

As we study the candidate missions, what criteria should guide our winnowing process? The President of the AAS, Debra Elmegreen, in the October 2010 AAS Newsletter, lists these attributes of a mission: (a) scientific merit, (b) technical readiness, (c) balance, (d) affordable cost, (e) tolerable risk. We will need all of these attributes to succeed. The question we can ask of each proposed mission concept is, how will it rank in these categories as we enter 2014?

6. Conclusions

While the ambitious space program envisioned by NWNH is unlikely to be realized in its entirety in the coming decade, largely as a result of the severe funding constraints facing NASA's Astrophysics Division, it is clear that NASA intends to follow the guidance provided by NWNH as best it can. Rapid progress in the area of exoplanetary science will continue to be made in 2010-2020 as a result of ongoing ground-based exoplanet discovery and characterization efforts, future space-based observatory-class telescopes such as JWST, and especially by ongoing exoplanet-specific space telescopes, namely Kepler and Europe's CoRoT Mission.

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