ExoPAG4 Summary
(June 1-2, 2011, Alexandria, VA)

About 40 exoplanet scientists and engineers attended the fourth ExoPAG meeting in Alexandria, VA. As at the previous meeting, the main topic of discussion was planning for a flagship-class direct imaging mission in the next decade. This does *not* imply that the ExoPAG is not interested in other, smaller exoplanet missions that might fly before this time. But the main focus should be on missions that help to pave the way for the direct imaging mission that we all have in mind and that was recommended for technology development by the Astro2010 survey.

Doug Hudgins began the meeting with a review of Kepler, along with remarks about the exoplanet program from the viewpoint of NASA Headquarters, based on his conversations with Jon Morse. Importantly, Morse has suggested that we may not need to make an official downselect of the architecture for the direct imaging mission by 2015. The combination of low budgets for the next few years and the delay in the launch of JWST means that any future flagship mission will likely be pushed out into the future by several years. Following this, Mike Devirian outlined NASA's plan to perform IPS (Imaging Performance Study) studies beginning this September, and funded ISWG (Interdisciplinary Science Working Group) studies beginning in January, 2013. This was the plan originally proposed by Doug Hudgins at the ExoPAG3 meeting in January. Both sets of studies are intended to assist NASA in selecting an architecture, *e.g.*, an internal coronagraph or an external occulter, for a future direct imaging mission. The IPS study is preliminary and non-binding, as discussed further below. Devirian's remarks triggered considerable discussion, with some arguing that an early downselect is still needed and others cautioning that we should wait until we understand the competing technologies better. Opinions within the room, and on the ExoPAG steering committee, varied on this issue. Some argued that starting ISWG studies in January, 2013, would be premature, as this would not allow sufficient prior technology development to make a rational choice between architectures. Others, including Devirian and Wes Traub from the Exoplanet Exploration Program Office argued that it is critical to make this downselect early so that if NASA's technology funding for this mission increases in mid-decade, as planned, it can be focused on a specific mission architecture. The ExoPAG did not reach a conclusion on this issue, nor do we feel that it is essential for us to do so. The ExoPAG provides a forum in which such issues can be discussed. It is up to NASA, with advice from the APS committee, to decide on the appropriate course of action.

Jim Kasting then gave a summary of the April 26 joint meeting between the ExoPAG and the COPAG. (COPAG is the Cosmic Origins Program Analysis Group.) COPAG is also interested in a large UV/optical/near-IR telescope in space. Some in the COPAG favor an 8-m aperture; others (the UV community in particular) would be satisfied with a 4-m aperture or smaller. Members of both PAGs feel that our chances of getting such a mission selected in 2020 will be optimized if we are proposing a single, joint mission at that time. The ExoPAG has agreed to consider 4-m and 8-m telescopes, at least until more information is available about η_{Earth} and the exozodi background. High values of η_{Earth} and low exozodi backgrounds would make a smaller telescope scientifically viable; low η_{Earth} and high exozodi would favor the larger telescope. Both parameters may be known within the next few years if Kepler continues to perform well

and if LBTI comes on-line during that time. A preliminary (and relatively low, 2.5%) estimate of η_{Earth} was given by Mike Shao on day 2 of the meeting, but the consensus of the listeners was that the Kepler data are currently incomplete for transits spanning multiple quarters of data. So, we just need to be patient and wait for the data to come in and for the necessary, cross-quarter analysis to be done.

The afternoon of day 1 was spent discussing the proposed IPS exoplanet detection study by the Exoplanet Exploration Program Office. This is meant as a preliminary (non-binding) assessment of the performance of different direct imaging architectures. Wes Traub and Steve Unwin led the discussion, with help from JPL engineers who are engaged in developing the algorithms that will be used to analyze the different types of direct detection methods. After hearing how this would be done, most in the audience agreed that this will be a useful exercise, although some argued that doing this as a blind study is premature. All agreed that it would be useful to compare and understand the algorithms used to measure the performance of different mission architectures. Importantly, as part of the study, each team will develop a DRM (design reference mission). Thus, the comparison between architectures will include demonstrating how many actual stars may be searched during the mission lifetime. The ability to switch quickly from one target star to the next should favor internal coronagraphs over occulters. That advantage could be offset, however, if the occulter does a better job of finding and characterizing planets once it is focused on a given star.

The morning of day 2 began with a continuation of the discussion of the science requirements for a direct imaging mission. (This discussion actually started on day 1.) Charley Noecker discussed the Kepner-Tregoe method of decision making, which he suggested could be used to compare different direct imaging missions. Certain science requirements, e.g., the ability to detect the Earth around the Sun at 10 pc, would be set as absolutes: if a mission could not meet them, then it would fail. Other requirements, e.g., the ability to take spectra of exoplanets in the UV and near-IR, would be assigned points. A mission that does well on these criteria would gain points; a mission that does poorly would lose points. In the end, the points generated from the science goals and requirements would be added to points assigned based on engineering concerns and costs in order to select the best mission architecture. The discussion on day 2 centered on which requirements should be considered as absolutes. Noecker endorsed starting from the existing TPF-C requirements and then modifying them as needed. This process has been started, but it is not yet complete. Email discussions and telecons will be needed over the next few months to iterate to a solution. Preliminary science requirements should be provided to the Exoplanet Exploration Program Office by the beginning of September for their proposed IPS study. A well-thought-out version of the science requirements should be presented to the ExoPAG at the next general meeting in January, 2012. Along with Level 1 science requirements, a set of science goals should be generated. Chuck Lillie suggested 3 such goals at the meeting. Jim Kasting circulated a list of 14 TPF-C science goals following the meeting. These goals should also be decided by iterating via telecon.

Following the discussion of direct imaging science goals, Aki Roberge and Chris Stark discussed the status of our knowledge of exozodis. As before, both speakers emphasized the hope that LBTI (the Large Binocular Telescope Interferometer) will provide much of the information that we need. LBTI should be able to measure exozodis

down to the level of about 10 zodis. Our current limit on exozodi detection is several hundred zodis, based on the Keck interferometers. Importantly, Zlatan Tsvetanov suggested that a balloon-borne telescope of some sort could measure exozodis and thus provide backup in case LBTI fails. This would require augmenting the balloon program in order to have enough money to fly such a mission. This might be another useful thing to do if sufficient money can be found.

Next, Lisa Kaltenegger discussed the plans for SAG4, which is tasked with defining the goals for exoplanet characterization. This task obviously overlaps with the SAG led by Noecker and Tom Greene, which is trying to define Level 1 science requirements for a direct imaging mission. SAG4 should generate a report soon, i.e., within the next few months. This is not difficult, as much of this work was done previously for TPF-C. UV science is new, however, and should be added.

Dave Bennett then provided an update on WFIRST and Euclid. Planning for Planning for WFIRST as a stand-alone mission is proceeding as recommended by Astro2010, but over the coming year this plan may be altered, depending on what ESA decides to do with Euclid. Microlensing should get a share of the mission regardless of how this works out. The WFIRST microlensing program will provide statistical knowledge of planetary systems extending outward from the habitable zone (which would be complementary to the information derived from Kepler). But this will probably not be in time to influence a 2020 decadal survey.

The final topic for day 2 was a discussion of technology funding for the exoplanet program. Tibor Balint from the NASA Chief Technologist's Office discussed how their monies are arranged. Their considerable (~$1B/yr) budget funds all manner of technologies across the manned and unmanned space program. The part that is relevant to astrophysics concerns cross-cutting technologies: things which are useful for multiple disciplines. Formation flying is one such example; plans for flying an occulter might fall into this category.

A second part of this technology session was headlined by a talk by Webster Cash. Cash suggested that a new mode of funding exoplanet technology is needed if we hope to get a flagship-class direct imaging mission selected by 2020. In particular, laboratory and flight demonstrations of key technologies, e.g., occulters, must be performed well in advance of this date. Cash suggested that the ExoPAG could help decide how NASA's technology funds should be spent. Chairman Kasting pointed out that the ExoPAG has no such authority, according to its charter. However, we do have the authority to write reports and submit them to the APS committee and to Jon Morse. Kasting tasked Cash with writing such a report and presenting it for approval at the ExoPAG meeting in January, 2012.