Date: **October 30, 2007**
To: **David Gross, Director KITP**
From: **Adam Burrows**
Re: **Proposal for a KITP Program on Exoplanets**

In response to your request for KITP program suggestions, we propose a comprehensive, 4-month program during the winter and spring of **2010, starting January 27 of that year**, entitled:

THE THEORY AND OBSERVATION OF EXOPLANETS.

The study of exoplanets has emerged in the last decade to be one of the most exciting new areas of astronomy and planetary science. Since 1995, more than 250 planets outside the solar system have been discovered, mostly by radial-velocity methods. Collectively, they span a huge range of masses and orbital distances, have been found around most stellar types, and have led to major revisions in our ideas of how and where planets form and what is their structure. The majority of these planets are gas giants, but more than 20 are of Neptune mass and lower. Twenty-four are known to transit/eclipse their primary star, and it is for these that we have physical parameters such as radius and mass. A subset of the close-in transiting giants has now been detected directly at secondary eclipse and at various orbital phases by the Spitzer Infrared Space Telescope, providing the first measurements of extrasolar planetary atmospheres and compositions. If funded, Spitzer will soon enter its post-cryogen observing phase, during which a major focus will be exoplanet studies.

The James Webb Space Telescope (JWST), the infrared successor to HST to be launched in the 2012-2014 timeframe, will have in its MIRI and NIRCam instruments 100 times the sensitivity of Spitzer's IRS, IRAC, and MIPS cameras for this same class of measurements. Soon, the satellites Kepler (to be launched early 2009) and CoRoT (launched Dec. 2006) will be detecting transiting Earths and super-Earths (some in the habitable zone of their host systems), and the astrometry satellite GAIA (to be launched in 2011) will reveal thousands of exoplanets around stars within 1000 parsecs. There are many new and ongoing NASA (and ESA) proposals at the SMEX, Discovery, and flagship mission levels to design and launch telescopes to directly or indirectly measure exoplanets. The number of ground-based programs and wide-field surveys to discover and characterize them has become too numerous to catalog. Hence, the pioneering era of exoplanets has commenced in earnest and promises to be a central focus of an increasing fraction of the world's astronomers for the foreseeable future.

In addition, astronomers are probing protostellar/protoplanetary disks to determine the origin and early evolution of planets and the contexts of their birth. Using infrared and sub-millimeter telescopes, questions are being asked and answered concerning planet migration, their thermal environments, planet-disk interactions, masses, and orbital properties, and we hope soon to learn why and where planets of all types arise.

To interpret these exoplanet data, theorists have developed models for planet formation, orbital interaction and dynamics, evaporation due to stellar irradiation, atmospheric circulation and global heat transport, atmospheric structure and spectra, phase light curves, the equations of state of their interiors, molecular chemistry, radius evolution, and tidal effects, to name only a few topics. Although some of these topics are mature, there continue to be novel ideas and major developments in theory and modeling motivated in many cases by the new range of parameters encountered in these exoplanets, and also motivated by the ongoing effort to understand the gas and ice giants in our own planetary system. For example, there have been recent advances in the understanding of the behavior of hydrogen and hydrogen-helium mixtures from both theory and experiment. In any case, the dialogue between the data and the models has entered a particularly fruitful stage - the upshot is the emerging science of comparative planetology, now with a few hundred examples, but soon with thousands.

A KITP program on exoplanets would accomplish two overarching goals. First would be the synthesis using theory of the vast amount of information already gathered to create a global picture of the field and its future. One byproduct of this effort would be the mutual education of theorists and observers to create a more coherent discipline of comparative planetology. This could help in the design of incipient NASA and ESA exoplanet research programs, but could also help guide future ground-based and space-based observing campaigns. Second, and perhaps more important, would be the further integration of planetary science into the astronomy of exoplanets. Surprisingly, to date exoplanet research has been driven by astronomers, while planetary scientists have by and large sat on the sidelines and focussed almost exclusively on our solar system. However, the expertise and accummulated wisdom in planetary science is vast, and the merger of its perspectives and knowledge with the new astronomical discoveries being made outside the solar system would greatly enrich both. Clearly, the collaboration and cross-pollination of these two communities is in their mutual, long-term interest - one goal of this program would be to facilitate this. One specific example of cross-fertilization might be in the context of NASA's Juno mission to Jupiter (scheduled for launch in 2011, just after our proposed program). One of the questions Juno seeks to address is whether Jupiter has a heavy element core and this issue ties in directly with the corresponding question for giant exoplanets.

In summary, our broader aims will be: 1) to summarize the current understanding of this very rapidly evolving, highly interdisciplinary field; 2) to present the latest ideas, models, techniques, and observations; 3) to foster the interaction of the planetary science and astronomical communities; and, 4) to identify crucial objectives and problems that will enable clear, coherent advancement of the field in the coming years.

- **Timeliness**:

The last KITP exoplanet program was in 2004 and was on "Planet Formation." Since then, Spitzer has measured photons from several hot Jupiters and obtained light curve variations with orbital phase. Water has been detected in some of their atmospheres, and putative "super-Earths" have been found. A stratosphere has been identified in the upper atmosphere of HD 209458b. A Neptune-mass planet has been discovered in transit and its photon flux measured. More than 20 ice-giant class planets have been catalogued.

Ice giants are of great interest both in our solar system as well as elsewhere. It could be argued that they are the most diagnostic of all bodies in respect of formation process since they involve both condensates and gas but are not overwhelmingly one or the other (as is the case for "Jupiters" or "Earths"). They also pose some fascinating questions for thermal history, internal mixing and high pressure physics of ice-gas-rock compositions; questions that we have not answered for Uranus and Neptune and will be timely both for our solar system and for the new discoveries and probably far larger data set in 2010.

The micro-satellite MOST has tightly constrained the optical albedo of several close-in giants. The number of known exoplanets has tripled. On the theoretical side, sophisticated atmosphere and spectral models have been created, 3D global circulation models are being developed, chaotic dynamical models of planetary orbits and migration are being perfected, new structural models of solid planets have been fielded, coupled migration and formation models of planets have been proposed, models to photometrically distinguish the various suggested modes of planet formation have been published, tidal heating models have been updated, models of the non-equilibrium chemistry of planetary exospheres have been developed, and more sophisticated thermal and evolutionary models of protostellar and protoplanetary disks are being generated and tested.

Therefore, with the promise of Kepler, CoRoT, GAIA, JWST, and the advent of numerous ground-based wide-field planet surveys, with the detection via gravitational microlensing of a handful of low-mass planets, and numerous proposals such as TIMEX, EPOXI, GIMLI, TOPS, and Eclipse (to name only a few) to loft space platforms dedicated to exoplanet research, the time is ripe for a broad-based and comprehensive Exoplanet Program at the KITP. Moreover, our proposed program would come fast on the heels of the publication of the recommendations of the 2010 Astronomy Decadal Survey (late 2009), and national plans for exoplanet research will thus have been clarified.

The only other related workshops of which we are currently aware will be held at Aspen in the summer of 2008 and at Les Houches this winter, starting February 2008. However, the first is focussed solely on "super-Earths" and terrestrial planets and is to last only 3 weeks and the second is to last only 2 weeks, is entitled "Physics and Astrophysics of Planetary Systems," and will focus on the solar system.

- **Coordinators**:

As coordinators, we have identified Adam Burrows (University of Arizona), Dave Stevenson (Caltech), and Kristen Menou (Columbia University). Each of these three coordinators plans to attend 3 or more months of the 4-month program and we will ensure that there is at least one coordinator (most of the time 3) in residence at any particular time. We have assigned Kristen Menou to serve as the diversity coordinator. These individuals have extensive experience organizing scientific meetings, and extensive experience with the KITP. Adam Burrows was the lead coordinator for a program in 1997 on Supernovae and participated in the planet formation workshop in 2004, and Kristen Menou has visited KITP repeatedly over the years. Dave Stevenson was lead organizer of a mini-workshop on high pressure physics applied to planets in 2001, participated in the planet formation workshop in 2004, and is very familiar with KITP activities and goals. This group will attract participants from diverse scientific backgrounds (e.g., astronomy, planetary science, and atmospheric science) to ensure the successful exchange of ideas and techniques.

- **Justification for Program Length**:

We justify the 4-month length of the program by the fact that we intend to cover the entire field of exoplanets. This includes giant planets, ice giants, and terrestrial planets (including super-Earths). It includes the connections with solar-system planetary science, models of solar-system bodies, and the concept of the habitable zone. It includes atmospheres, spectroscopy, chemistry, interiors, equations of state, evolution, and formation. It includes orbital dynamics, resonances, tidal effects, and migration. It includes stratospheres, exospheres, and mass loss. It includes general circulation models, jet streams and heat redistribution, 2D and 3D simulations, and time-dependent chemistry. And, it includes a comprehensive review of the entire observational context that theorists are struggling to interpret and understand. Of course, all these topics are connected and we seek to develop an integrated view of the field - one that, if we are successful, will emerge from the program and filter into the community to inform its future.

- **Conference**:

It will be very useful to have a 3- to 5-day conference during the program. We have yet to decide on whether it should be at the beginning, the middle, or the end, but we are leaning towards the middle. In this way, the participants can afterwards take full advantage of the talks given by non-participants, while the early weeks can be used to establish the zeitgeist of the program and to settle in.

- **Possible Participants**:

Some of the key participants might be: E. Agol, T.J. Ahrens, R. Angel, P. Arras, Jonathan Aurnou, G. Bakos, Steve Balbus, I. Baraffe, Travis Barman, W. Benz, L. Bildsten, Peter Bodenheimer, A. Boss, F. Bouchy, T. Brown, A. Burkert, Paul Butler, R. Canup, G. Chabrier, David Charbonneau, James Cho, Drake Deming, I. Dobbs-Dixon, J. Elliot, Debra Fischer, Jonathan Fortney, R. Freedman, Scott Gaudi, P. Goldreich, Richard Goody, Tristan Guillot, O. Guyon, Bradley Hansen, Joseph Harrington, Matthew Holman, B. Hubbard, I. Hubeny, R. Jeanloz, M. Konacki, H. Knutson, Helmut Lammer, Gregory Laughlin, Douglas Lin, R. Lindzen, J. Lissauer, Geoff Marcy, R. Mardling, Mark Marley, Michel Mayor, B. Millitzer, B. Murray, Richard Nelson, F. O'Donovan, Gordon Oglivie, John Papaloizou, Didier Queloz, Fred Rasio, Larry Rothman, Dimitar Sasselov, D. Saumon, Sara Seager, Adam Showman, Dave Stevenson, M. Swain, Caroline Terquem, G. Tinetti, G. Torres, J. Trauger, Ashwin Vasavada, W. Ward, Alycia Weinberger, Josh Winn, J. Wisdom, and Yuk Yung.

Women in the above list whom we are particularly interested in encouraging to attend are:

G. Tinetti, H. Knutson, R. Mardling, S. Seager, I. Baraffe, D. Fischer, C. Terquem, and R. Canup.

People whose focus has been in traditional planetary sciences whom we would target are:

T.J. Ahrens, A. Boss, J. Elliot, P. Goldreich, R. Goody, T. Guillot, B. Hubbard, R. Jeanloz, R. Lindzen, J. Lissauer, R. Mardling, B. Millitzer, B. Murray, G. Oglivie, J. Papaloizou, A. Showman, D. Stevenson, A. Vasavada, W. Ward, J. Wisdom, Y. Yung

Given the fast pace of discovery, there will be many new planets and follow-up observations to interpret. Hence, we firmly believe that this proposed program would be a highly anticipated and successful one. We look forward to hearing from you concerning this suggestion.

Regards,

Adam Burrows, Dave Stevenson, and Kristen Menou