Transiting Planets
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The Impact of Transiting Planet Science on the Next Generation of Direct-Imaging Planet Searches

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Abstract. Within the next five years, a number of direct-imaging planet search instruments, like the *VLT SPHERE* instrument, will be coming online. To successfully carry out their programs, these instruments will rely heavily on a-priori information on planet composition, atmosphere, and evolution. Transiting planet surveys, while covering a different semi-major axis regime, have the potential to provide critical foundations for these next-generation surveys. For example, improved information on planetary evolutionary tracks may significantly impact the insights that can be drawn from direct-imaging statistical data. Other high-impact results from transiting planet science include information on mass-to-radius relationships as well as atmospheric absorption bands. The marriage of transiting planet and direct-imaging results may eventually give us the first complete picture of planet migration, multiplicity, and general evolution.

1. Examples of Upcoming Direct-Imaging Planet-Search Systems

Ground-Based

- *HiCIAO*: An adaptive optics coronagraphic simultaneous-differential-imager for the Subaru 8.2 meter telescope (Tamura *et al.* 2006); currently in commissioning phase.
- *Project 1640*: An adaptive optics coronagraphic integral field spectrograph for the Palomar 5 meter Telescope (Hinkley *et al.* 2008); currently in commissioning phase.
- *SPHERE*: An adaptive optics coronagraphic simultaneous-differential-imager and integral field spectrograph for one of the VLT 8.2 meter telescopes (Beuzit *et al.* 2008); commissioning expected 2011.
- *GPI*: An adaptive optics coronagraphic integral field spectrograph for the Gemini South 8 meter telescope (Macintosh *et al.* 2006); commissioning expected 2011.

Space-Based

- *Terrestrial Planet Finder Coronagraph*† *?*
- *Terrestrial Planet Finder Interferometer*‡*/Darwin*¶ *?*

All of these systems will rely on results from transiting planet science to accurately interpret their observations.

† http://planetquest.jpl.nasa.gov/TPF-C
‡ http://planetquest.jpl.nasa.gov/TPF-I
¶ http://www.esa.int/science/darwin

2. How Transiting Planet Radius Estimates Affect Direct-Imaging Results

Direct-imaging surveys, that observe the thermal emission from planets, are unable to make a direct measurement of planet radius. In order to convert an observed magnitude into a planet temperature they must therefore usually rely on a-priori knowledge of typical planet radii (for a given planet mass). Results from transiting planet surveys (see compilation in Bakos *et al.* 2004 for instance), however, suggest that typical planet radii could be larger than researchers have previously presumed. More data from transiting planet surveys are required to better establish this mass-radius relationship. The conclusions from such data will be important for accurately determining the sensitivities of direct imaging programs. The plot below shows how estimated direct-imaging sensitivities (minimum detectable mass as a function of separation from the parent star) may be affected by changes in planet radii assumptions

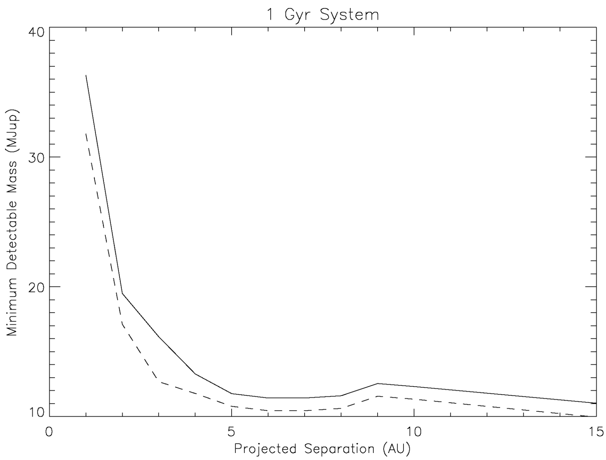

Figure 1. This plot shows how estimated (near-IR) direct-imaging high contrast sensitivities may be affected by errors in a-priori assumptions of typical planet radii. The solid curve assumes a conventional mass-radius relationship (e.g. a 1 M_{Jup} planet has a 1 R_{Jup} radius). The dashed curve corresponds to the case where actual typical planet radii are 25% larger than classical models assume. For the displayed 1 Gyr system, the expected minimum detectable mass at 1 AU changes from $\sim$36 M_{Jup} to $\sim$32 M_{Jup}. This disparity becomes smaller for younger systems and larger for older systems. The plots assume a high-contrast sensitivity curve adapted from example *VLT SPHERE* simulations for a target system 10pc away. Planet masses are derived from temperature and age using Baraffe *et al.* (2004) models. For a given mass and age, all planets are assumed to have identical atmospheric optical depths.

Figure 2 (from *SPHERE* internal documentation) shows a model atmospheric spectrum for a 1 M_{Jup} 10 Myr planet (solid black curve). Simultaneous differential imagers can identify planets by comparing the flux in two adjacent narrow bands (like the H2 and H3 bands shown on the plot) and searching for the signature absorption drop. To understand the sensitivity of this technique to planetary masses, one must first predict the expected planet flux drop between the two narrow-band filters. While theoretical models predict such flux changes, transiting planet observations provide empirical data to test such assumptions. Integral field spectrographs go one step further by imaging a potential star planet system as well as taking a low resolution (like R$\sim$50) spectrum at each point in the image. A planet signal may be identified by running a correlation analysis between the observed spectrum and an expected planet spectrum. An error in the prediction of

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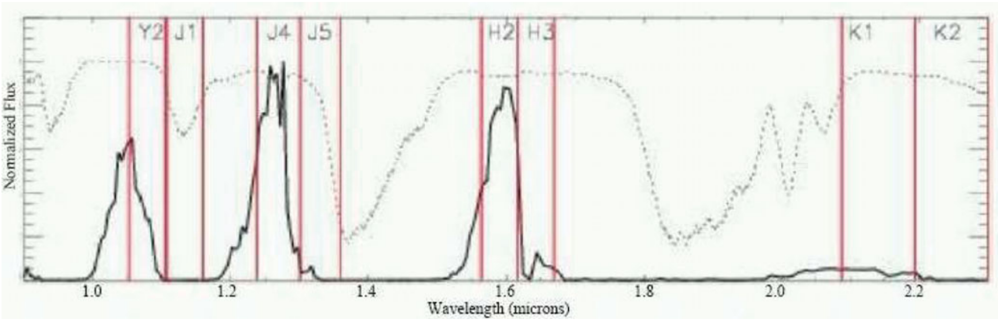

Figure 2. A model $1M_{Jup}$ planet spectrum (solid curve) with narrow band filters (vertical red lines) shown on top. Figure from *SPHERE* internal documentation.

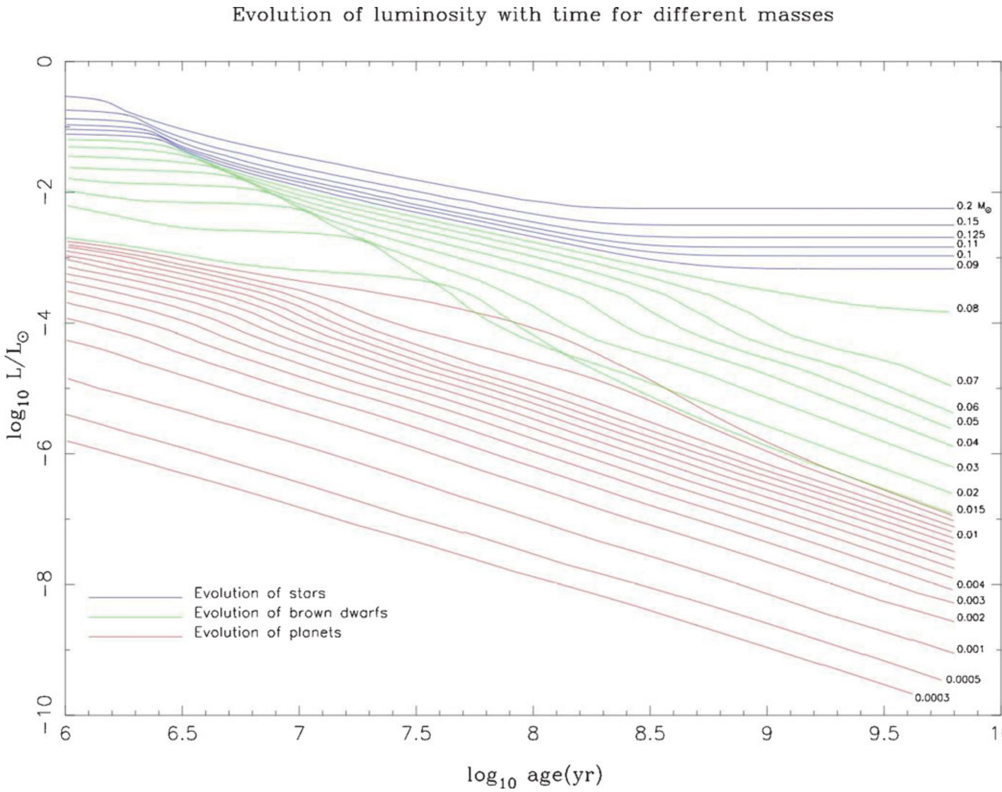

Figure 3. Evolutionary cooling models by A. Burrows for M dwarfs (blue curves), brown dwarfs (green curves), and exo-solar giant planets (red curves). Plot from http://www.astro.princeton.edu/∼burrows.

expected planet spectra would lead to a degradation in sensitivity. Transiting planet atmospheric studies would therefore be helpful in improving these correlation analyses.

For direct-imaging detections, the planet mass must typically be derived indirectly via theoretical evolutionary models like the one shown in Figure 3. Transiting planet data, in their capacity to help improve these evolutionary tracks, may therefore lead to better direct-imaging planet mass estimates.

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3. Complementarity Between Transit and Direct-Imaging Planet Observations

While transiting planets are unlikely to be successfully observed with direct-imaging techniques, transiting planet systems nevertheless make appealing targets to search for wider orbit planets. Indeed, the discovery (via direct-imaging) of an outer planet around a transiting planet system would make an exciting case to observe planet multiplicity through a large semi-major axis range. As planet detections via these techniques reach a statistically significant number, the results should allow us a more complete picture of inward/outward migration, planet multiplicity, dynamical equilibrium, and general planet evolution.

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