HARPS-N White Paper

Description of the scientific use of HARPS-N

The HARPS-N Consortium

The HARPS-N Consortium is a collaboration between various institutes of different countries for the construction and operation of HARPS-N. The HARPS-N instrument is a high-precision spectrograph, equivalent to the existing HARPS on the 3.6-m ESO telescope in Chile. It will be located in the Northern hemisphere at the Telescopio Nazionale Galileo (TNG), located at the Spanish Roque de los Muchachos Observatory, to allow for synergy with the NASA Kepler mission.

Scientific Rationale for HARPS-N

The main scientific goal of the HARPS-N Consortium is the discovery and characterization of terrestrial exoplanets by achieving long-term sub-meter per second radial-velocity precision on V<12-mag stars.

HARPS-N is a high-resolution (R=120,000) optical spectrograph with broad wavelength coverage (378-691 nm). In order to understand it capabilities, one can use the existing HARPS instrument (on the 3.6-m ESO telescope) as a baseline. However, HARPS-N is expected to benefit from updates and improvements.

The following is a description of the projects the HARPS-N Consortium plans to do during the first 5 years after the instrument is commissioned.

Primary Scientific Objectives

Primary Project - Synergy with Kepler

NASA's Kepler mission was launched in March 2009. Kepler monitors a single field in Cygnus/Lyra (RA=19:23, Dec=+44.5) for at least 3.5 years and has already identified nearly a thousand transiting planet candidates orbiting preselected main sequence stars (F to M type) of V= 11-15 mag. Kepler is capable of detecting dozens of Earth-sized planets in orbits with periods up to about one year, as well as several hundred super-Earths. To confirm and characterize the rocky planets identified by Kepler, it is critical to determine orbital solutions so that the planetary masses can be established. With its ability to measure velocities with a precision better than 1 m/s, HARPS-N will provide a unique capability for determining the masses of Kepler planets similar to the Earth.

Primary Project Goals

The primary project of the HARPS-N Consortium has three broad scientific goals that can be achieved by delivering planetary masses of certain precision:

A. confirming an Earth-twin planet in the habitable zone of a G5V star or later, with a precision of 30% in mass;
B. characterizing Earth-like planets of 2-5 Earth masses ("super-Earths") in various orbits with enough precision to distinguish between water-rich and dry planets;
C. characterizing the transition between super-Earths and Ice Giants (hot Neptunes, for example) near 10 Earth masses, with a precision of 5% in mass, or better.

For planets in the classes for goals (b) & (c), Kepler will determine planetary radii with a precision of 5% or better, for stars in the "sweet spot" around V=12 mag and brighter. For the Earth-like planets in goal (a), Kepler could provide 15% in radius precision. All these estimates improve considerably for M-stars, but the probability of discovery is assumed low because of the small number of M-star target stars. These values: 5% in radius, and (a), (b), & (c) in mass, allow achieving our goals, as shown by the theoretical models (Valencia, Sasselov, O'Connell 2006, 2007; Fortney et al. 2007). Note that achieving goal (b) is essential, in a boot-strapping sense, to achieving confidence in completing goal (a), and hence of achieving Kepler's legacy as a whole. HARPS-N in the Doppler domain is a true match to Kepler in the photometric domain, thus providing vastly improved planetary mean densities for a meaningful comparison to interior models.

Primary Project Observing Time Requirements:

HARPS-N on a 4-m class telescope in the Northern hemisphere (e.g. TNG) can achieve the above tolerances in mass determination with a certain number of Doppler measurements. That number of observations can be evaluated under the following set of conditions. First, the Kepler light curve constrains the period and phase of the planet's orbit. Second, we select targets of V=12 mag or brighter, for which HARPS-N should achieve 1.0 m/s in 1 hour. This has been demonstrated with the HARPS in Chile. We illustrate our estimate of the required number of observations to achieve 10% in planet mass at a 0.10 AU orbit in the table below:

Star	5 M_{EARTH}	10 M_{EARTH}
F0 (1.60 M_{SUN})	158	40
G0 (1.05 M_{SUN})	104	26
K0 (0.79 M_{SUN})	78	20

M0 (0.51 M_{SUN})	50	13

With such estimates in hand, we have determined the number of effective clear observing nights (HARPS-N on TNG) required to accomplish the three goals of our Primary Project:

1. for 2 planets (over 3 years) - 160 h = 16 nights per year
2. for 20 planets in various orbits - 250 h = 25 nights per year
3. for 20 planets in various orbits - 210 h = 20 nights per year

Primary Project Scheduling

The 61 clear nights per year estimated above fall within the season of about seven months (April through October) when the Kepler field is easily accessible from the TNG. Flexible scheduling of partial nights is an advantage, because it allows the observing season to be extended, and because it allows observations of specific targets to be scheduled at optimum times in their orbits.

The Kepler mission has already identified sufficient numbers of candidate planets in all three categories of the Primary Project to allow us to pick the optimum ones for follow up with HARPS-N.

The Kepler mission has formally recognized the role of HARPS-N in achieving the mission goals, and has committed to seek resources to support the use of HARPS-N for Kepler follow up.

Secondary Project - Earth-Like Planets Around Nearby Stars

HARPS-N will be capable of better than 20 cm/s precision and stability for very bright stars. The HARPS-N Consortium plans to observe a sample of the brightest, least active, and least noisy northern stars. The goal is to discover Earth-like planets and multiple planet systems. The value of such discoveries is that a number of exciting follow-up possibilities become possible for such nearby objects. While bright stars do not require very long exposure times, in order to achieve long-term precision below ~50 cm/s we have to devote additional observing time to characterize the stellar p-mode oscillations, granulation noise power, and rotation induced variations. Judging from our current experience, this project will require at least 10 - 20 clear nights per year, in order to be scientifically viable. We anticipate that the primary targets for this project can be identified before any observing with HARPS-N begins.

Synergy with TESS and PLATO

The Transiting Exoplanet Survey Satellite (TESS) is a space mission to survey the entire sky to discover the nearest and brightest transiting exoplanet systems, namely the best ones for follow up with future missions such as the James Webb Space Telescope (JWST). TESS was selected for a Phase A study for a NASA Small Explorer in May 2008, but was not selected for a flight opportunity in June 2009. A proposal to the upcoming NASA Explorer Announcement of Opportunity is under active preparation by an MIT-CfA-NASA team. The nominal schedule calls for the launch of TESS in June 2016. PLAnetary Transits and Oscillations of Stars (PLATO) is an M-Class candidate mission with similar goals now being studied for the ESA Cosmic Visions 2015-2025 opportunity and a possible launch as early as 2018.

HARPS-N will allow Doppler follow-up for the large number of Neptune-like and sub-Neptune planets TESS and/or PLATO will discover. Because the systems discovered by these missions will be much brighter than the vast majority of the Kepler planets, it will be possible to determine masses for smaller planets. The TESS/PLATO planets will be the best targets for future research on transiting planets, such as studies of the planetary atmospheres and weather with JWST. Both missions have expressed a strong interest in using HARPS-N for follow-up observations.