Habitable Earth-like planet surveys with next generation extremely high resolution and high Doppler precision optical and near IR spectrographs

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From Stars to Life, 4/5/2013
Discovery of a potential habitable planet around M dwarf, GL 581, with HARPS on ESO 3.6m (Mayor et al. 2009)
Discovery of a possible Habitable World Elsewhere with Kepler (Borucki et al. 2011)

- Kepler-22 (G5V, V=11.5, 180pc), Kepler-22b (P=289.9 days, 0.85 AU, 2.4R⊕)
- It may have ~10-30 Earth masses depending on its density, ~1 m/s RV amplitude
Kepler’s Planet Candidates
22 Months: May 2009 - Mar 2011

Radius Relative to Earth

Orbital Period in days

1 m/s detection limit

Chris Burke: 216.02
Occurrence of Planets

Fressin et al. 2013, AAS

FRACTION OF STARS WITH AT LEAST ONE PLANET

PLANET SIZE (relative to Earth)
Habitable Zones among K & M Dwarfs and Doppler Sensitivities

- RV precision $\leq \sim 1$ m/s required to probe habitable super-Earths around K0V-M4V dwarfs
- RV precision $\leq \sim 3$ m/s required to detect habitable super-Earths around M4V-M9V dwarfs

Barnes 2012
RV Uncertainties Limited by Photons with R=120K at Different Bands

- High precision and high resolution optical spectrographs are needed for habitable planet surveys around K0-M4V dwarfs
- High precision and high resolution near IR spectrographs are needed for habitable planet surveys around M4V-M9V dwarfs

Wang & Ge 2012
EXPERT-III for Extremely High Precision RV Measurements at the KPNO 2.1m Telescope

Thermal enclosure, vacuum chamber and optical bench

- $R \approx 100,000$ & $50,000$ at 3800-9000Å
- an R4 echelle with 1-4 fiber image slicer to reach $R=100K$
- 6% total detection efficiency
- Vacuum operation (< 0.01 torr and high precision temperature control (~2 mK over one month)
- 0.4 m/s photon limiting precision in 15 min for a V=8 solar type star
- Total construction cost within $1M$

Major remaining tasks: Vacuum system refining, System optimization & Acceptance test
Lab First light R=100K Sky Spectrum Taken with EXPERT-III

- Order 161, 0.38 μm
- Order 68, 0.90 μm

ThAr emission spectrum

2x2 40 μm fiber bundle
Lab First Light R=50K Sky Spectrum

Order 161, 0.38 μm

Order 68, 0.90 μm
Reduced R=100K Solar Spectrum with EXPERT-III

Solar Spectrum Taken with EXPERT-III

Simulated Solar Spectrum

R=120,000

R=100,000
• RMS with 30 spectral orders combined ~ 5m/s, consistent with prediction
• Next test: vacuum with the R=100K mode to reach sub m/s calibration precision
Target Information for EXPERT-III Rocky Planet Survey at the KPNO 2.1m Telescope

274 M4-K0V V<8.5 Dwarfs in 2013-2017

$T_{\text{eff}}$ Distribution of Selected Survey Targets
EXPERT-III Doppler and Survey Sensitivity

Survey Sensitivity for low mass habitable planets (24 RV points)

Photon limited Doppler Precision at S/N =100 at 5500 Å

Pessimistic Performance

Predicted overall RV measurement errors

Baseline performance

<table>
<thead>
<tr>
<th>Number of planets</th>
<th>Superearths (&lt;10 M⊕)</th>
<th>Intermediate mass planets (10 M⊕-100M⊕)</th>
<th>Giant planets (&gt;100M⊕)</th>
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<tr>
<td>Baseline</td>
<td>17</td>
<td>22</td>
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<tr>
<td>Pessimistic</td>
<td>9</td>
<td>20</td>
<td>10</td>
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FIRST IR Doppler Instrument Development

**FIRST Chamber and Optical Bench**

- **R=68K at 1.4-1.8 \( \mu \)m and R=56K at 0.8-1.35 \( \mu \)m, overall detection efficiency \(~7\%\)**
- **Operated in a vacuum chamber (<0.01 torr for 1 month) at 193K for the bench and 77K for a H2RG array and temperature controlled to within \(~4\) mK over a month**
- **A silicon immersion grating (1.4-1.8 \( \mu \)m) and a R4 echelle (0.8-1.35 \( \mu \)m) with a mirror image slicer**
- **Compact design (0.5x1.0x0.4m dimension) to keep the total cost within $1.5M**
FIRST Spectral Format and Engineering Data in November 2012

Image quality and throughput meet requirements

Remaining major tasks before commissioning this summer:
• Install the image slicer
• Integrate the H2RG with the instrument
• Cryogenic cooling and vacuum testing
• Acceptance test
FIRST Cryo-cooling Test in March 2013

- Ready for the first system testing
FIRST Low Mass Planet Survey Target Information

215 M2-M9 J<10 Dwarfs in 2013-2017

$T_{\text{eff}}$ Distribution of Selected Survey Targets
FIRST at Fairborn Observatory to Hunt for Habitable super-Earths around 215 J<10 Late M Dwarfs in 2013-2017

Simulated Doppler Precision

Baseline with 30 min exposures
Pessimistic case w 30 min exposures

HARPS M dwarf sensitivity (Bonfils et al. 2011)

FIRST Exploration Space
(24 RV points)

- High cadence and queue schedule with the AST 2m robotic telescope offers the great flexibility for hunting for super-Earths
- Expect to detect ~30 exoplanets, including 10 super-Earths, within 100 day periods
Summary

• EXPERT-III has been assembled in the lab and is being tested and refined
• EXPERT-III will be commissioned at the KPNO 2.1m in June 2013
• EXPERT-III will be used for three key projects: Habitable super-Earth searches around early M and K dwarfs, SDSS-III MARVELS planet and brown dwarf candidate follow-ups and Kepler candidate follow-ups

• FIRST has been integrated in the lab and engineering data shows its optical performance meets requirements
• FIRST vacuum and thermal performance is being tested
• FIRST will be commissioned in June 2013, a pilot survey will be launched in fall 2013 and a full survey of ~200 nearby M dwarfs for habitable super-Earths will be carried out in 2014-2017

• Both FIRST and EXPERT-III are optimized for high spectral resolution, broad wavelength coverage and high throughput, but low cost (~$1M)

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