Next Generation High Resolution and High Doppler Precision Optical and Near IR Spectrographs

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Team Members

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Maui Double Star meeting, 2/10/2013
First Generation RV Instrument: Multi-object MARVELS at SDSS telescope with 60 Object RV Capability

MARVELS team in 2008

SDSS 2.5m wide field telescope

CT1 enclosure

Calibration box

Interface and Control System

Temperature control: ~10mK over 1 month

MARVELS has observed ~3300 FGK stars with V=7.6-12 in 2008-2012, with each observed ~27 times over 2 years
Some of the Published Substellar Companions in MARVELS

MARVES-1b, M=28.0M_J, P=5.9 days, e=0.0  

MARVES-4b, M=40.0M_J, P=9.0 days, e=0.23  
Ma, Ge, et al. 2012, AJ

MARVES-6b, M=31.7M_J, P=47.9 days, e=0.14  

MARVES-5b, M=65.0M_J, P=90.3 days, e=0.44  
MARVELS Starts to Fill its Designed Landscape

![Graph showing the distribution of planet candidates across different periods and minimum masses. The graph includes markers for MARVELS binaries, MARVELS BDs, and early planet candidates.]
MARVELS Doppler Instrument principle: Dispersed Fixed-delay Interferometry (DFDI)


Doppler shift: $\Delta V \propto \Delta \Phi$ (phase shift)
DFDI principle

Credits: Julian van Eyken
Second Generation RV instrument: EXPERT at Kitt Peak 2.1m telescope in 2009, motivated by MARVELS follow-ups

Temperature controlled: ~10mK over ~1 year
Pressure controlled: 1mpsi over ~1 year
LiJET Commissioning at the LiJiang 2.4m in Feb. 2011

LiJET UF team

LiJET chamber

Control System

LiJET telescope interface
Current Instrument Performance and Network Status

- EXPERT has its science operation since June 2010
- LiJET (EXPERT clone) was commissioned at the LiJiang 2.4m telescope in Feb. 2011 and completed telescope trial observations by January 2012.
- Working on data pipeline to reach a long term RV precision of 1-2 m/s
- Working on low mass planet survey simulation to come up with a survey plan, strategy, and cadence

Calibration
RMS=0.99 m/s

Sky measurements
RMS=2.8 m/s
New Era of Habitable Planet Searches

Gl581: M3V, 22 light year (~7 pc)

Gl581d (~7 M⊕, P = 66.8 days)

Mayor et al. 2009

KEPLER-22 SYSTEM

Kepler-22 (G5V, V=11.5, 180pc), Kepler-22b (P=289.9 days, 0.85 AU, 2.4 R⊕)

Borucki et al. 2012

EO 3.6m at La Silla and HARPS
Habitable Zones among M & K Dwarfs and Doppler Sensitivities

- RV precision $\leq \sim 3 \text{ m/s}$ required to detect habitable super-Earths around M4V-M9V dwarfs
- RV precision $\leq \sim 1 \text{ m/s}$ required to probe habitable super-Earths around K0V-M4V dwarfs
• 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
FIRST IR Doppler Instrument Development

FIRST Chamber and Optical Bench

• R=68K at 1.4-1.8 μm and R=56K at 0.8-1.35 μm, 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 μm) and a R4 echelle (0.8-1.35 μm) with a mirror image slicer
• Compact design (0.5x1.0x0.4m dimension) to keep the total cost within $1.5M

AST 2m Robotic Telescope at Fairborn Observatory
FIRST Spectral Format and Engineering Data in November 2012

Image quality and throughput meet requirements

Remaining major tasks before commissioning late this spring:
• Install the image slicer
• Integrate the H2RG with the instrument
• Cryogenic cooling and vacuum testing
• Acceptance test
FIRST at Fairborn Observatory to Hunt for Habitable super-Earths around 200 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

• 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
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 $3800-9000\text{Å}$
- an R4 echelle with 1-4 fiber image slicer to reach $R=100K$
- $\sim 8\%$ total detection efficiency
- Vacuum operation (0.01 torr over 1 month and high precision temperature control ($\sim 2\text{ mK over one month}$)
- $\sim 0.4 \text{ m/s}$ 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

Wavelength (Å)

Intensity

R^100,000

Wavelength (Å)

Simulated Solar Spectrum

Intensity

R=120,000
EXPERT-III  Doppler and Survey Sensitivity

Survey Sensitivity for low mass habitable planets

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

Baseline performance

Pessimistic Performance

Predicted overall RV measurement errors
Main Science Objectives:

• Search >200 FGK dwarfs with V<8 for low mass planets, including habitable rocky planets with a few Earth masses

• Follow up MARVELS and Kepler planet candidates
Summary

• Three generation high precision RV instrument and technologies have been developed at UF

  ❑ Dispersed fixed-delay interferometry (DFDI) with R~5-20K has multiplicity advantage: ~9 times speed gain over high resolution echelle spectrometer to obtain multi-object moderate high precision RV measurements for a fixed detector size

  ❑ High resolution echelle spectrograph has ~2 times precision advantage over the DFDI instrument for a fixed wavelength coverage

• The UF 3rd generation high resolution IR and optical spectrographs are being tested and will be commissioned late this spring:

  ❑ FIRST silicon immersion grating spectrometer in vacuum and with temperature control will be used for a survey of ~200 nearby M dwarfs for habitable super-Earths in 2013-2017

  ❑ EXPERT-III high resolution optical spectrograph in vacuum and with temperature control will be used for habitable super-Earth searches around ~200 early M and K dwarfs, SDSS-III MARVELS and Kepler candidate follow-ups

• Future global network high precision RV instruments require compact, low cost, robust and robotic operation: the DFDI instrument is an attractive option

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