Design Requirements for Precision Radial Velocimetry

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(on behalf of John Johnson)
“Conduct Advanced Telescope Searches for Earth-like Planets and Habitable Environments Around Other Stars”
— A Renewed Spirit of Discovery — President George W. Bush January 2004
Radial Velocities
10 cm/s
Howard et al. (2012)

Statistics from *Kepler*
Equilibrium Temperature [K] vs. $M_{\sin(i)}$ [Earth Mass]

Equation:

$$255 * (\text{Radius of Star [Solar Radii]}^{1/2} * (\text{Mass of Star [Solar Mass]}^{1/6} * (\text{Orbital Period [Days]} / 365)^{-0.3333} * (T_{\text{eff}}[\text{Kelvin}] / 5777))$$

Exoplanets with radial velocity measurements

First Publication Date

10/13/2012
Exoplanets with radial velocity measurements

$$255 \times (\text{Radius of Star [Solar Radii]})^{(1 / 2)} \times (\text{Mass of Star [Solar Mass]})^{(-1 / 6)} \times (\text{Orbital Period [Days]} / 365)^{(-0.3333)} \times (\text{T}_{\text{eff}}[\text{Kelvin}] / 5777)$$
Precision Radial Velocity Requirements

• **Photon Noise**
  – Telescope Area * N nights per year
  – Spectrometer Resolving Power (R>50k)
  – Spectrometer simultaneous bandwidth (~100s nm)

• **Systematic Noise**
  – Stability and calibration (~1 um physical)
  – Stellar jitter. Rotating spots and p-modes
    • Stationary noise process, overcome with high *cadence*
Precision Radial Velocity Requirements

- **Photon Noise**
  - Telescope Area $\times$ N nights per year
  - Spectrometer Resolving Power ($R > 50k$)
  - Spectrometer simultaneous bandwidth ($\sim 100s$ nm)

- **Systematic Noise**
  - Stability and calibration ($\sim 1\mu m$ physical)
  - Stellar jitter
    - Rotating spots and $p$-modes
    - Stationary noise process, overcome with high cadence

Optimize by **CALCULATION**

Optimize by **SIMULATION and EXPERIMENT**
• Quantitatively assess survey yield as a function of Doppler spectrometer specifications:
  – Resolution
  – Wavelength coverage
Photon Noise
(fundamental limit)
Relative Doppler precision for fixed integration time, star at 10 pc

Bottom et al. submitted
Relative integration time to detect a planet in the HZ, star at 10 pc
Relative integration time to detect a planet in the HZ, star at 10 pc
Relative integration time to detect a planet in the HZ, star at 10 pc

Bottom et al. submitted

Habitable Planet Finder (HPF)

G, K and early M Stars

mid-to-late M Stars

Iodine Gas Cell

HARPS

CH₄ NH₃ Gas Cells
RECONS 7 pc Sample

Mike calculated number of stars you can survey for 5 M\textsubscript{Earth} planets in the HZ for fixed observing time and tele size
• Mike calculated number of stars you can survey for 5 $M_{\text{Earth}}$ planets in the HZ for fixed observing time and tele size.
Iodine-Calibrated Regime

• 500 to 620 nm best place to search for habitable-zone planets around nearby G, K & early-M dwarfs via the Doppler method.

• But so far we have only considered photon noise
Systematic Noise

(defined as a noise source we cannot isolate)
HIRES Radial Velocity Measurements of Sigma Draconis
15 years of observations
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Averaging measurements does not improve RS residuals < 30 cm/s
HIRES Radial Velocity Measurements of Sigma Draconis
15 years of observations

1) Instrumental Variation?
2) Stellar Jitter?
3) Planets?

Averaging measurements does not improve RS residuals < 30 cm/s
Instrumental Profile Stability: Dominant Effect

Bottom et al. submitted 0.5 m/s floor for $10^{-3}$ skewness

Bottom et al. *submitted*
Instrumental Profile Stability: Stabilize with Fiber Scrambling

RV precision for Tau Ceti

Fisher, Tokovinin, Schwab, Spronck
Supported by NSF MRI, NSF and NASA
That Leaves **Jitter** and **Short-period Planets**

- Both can be overcome with *high-cadence* observations.
- An RV measurement *every night*.
- Project *Minerva*
Radial Velocities
10 cm/s

- IP Stability
  - Iodine + Fiber
- High Cadence
  - Dedicated instrument and telescope

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Future of Radial Velocities

- High TRL barge is headed towards big dedicated spectrographs, big telescopes, laser combs...

- ...but low TRL speed boats are fun
New Low TRL Project: LAEDI

- Lock-in Amplified Externally Dispersed Interferometer
- 2012 JPL DRDF award winner!
- P. Muirhead, G. Vasisht (Co-Pis), K. Wallace, R. Jensen-Clem, M. Bottom, J. Johnson
New Project: LAEDI

- Uses a zero-readnoise detector
- Single-mode fiber feed for high coherence
- Frequency locked-laser for mm/s OPD calibration.
New Project: LAEDI

Spectrograph first light on FRIDAY!
Thanks to students Rebecca Jensen-Clem and Michael Bottom
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- IP Stability
  - Iodine + Fiber
- High Cadence
  - Dedicated instrument and telescope
- Low TRL experiments

Exoplanets with radial velocity measurements