Towards the Detection and Characterization of Smaller Transiting Planets

David W. Latham
27 July 2007
Kepler MISSION CONCEPT

- *Kepler Mission* is optimized for finding habitable planets (10 to 0.5 M$_\odot$) in the HZ (out to 1 AU) of solar-like stars
- Monitor 100,000 main-sequence stars
- Use a one-meter Schmidt telescope:
  - FOV >100 deg$^2$ with an array of 42 CCD
- Photometric precision: < 20 ppm in 6.5 hours for $V = 12$ solar-like star
  - => 4$\sigma$ detection for Earth-size transit
- Mission: Earth-trailing orbit for continuous viewing, $\geq$ 4 year duration
Kepler Input Catalog

- Used to select optimum targets
- Includes all known stars in Kepler FOV
  - ~ 10 million stars (USNO-B)
- Photometry
  - 2MASS JHK + SDSS griz + D51
  - ~ 2 million stars down to K~14.5 mag
- Astrophysical characteristics
  - Teff, log(g), [Fe/H], reddening; Mass, Radius
  - Radial and rotational velocities
Transit Photometry

- Transit observations are hard to schedule
  - Solution: combine time with Kepler photometry
- KeplerCam light curves published:
  - TrES-1, HD 149026, HD 189733, XO-1,
  - TrES-2, HAT-P-1, WASP-1, WASP-2
- Submitted:
  - TrES-3, HAT-P-2, HAT-P-3
- Coming:
  - TrES-4, HAT-P-4
Fig. 1.— The upper panel shows the unbinned HATNet and WHAT joint light curve with 26400 data-points, phased with the $P = 5.63341$ d period. The 5mmag deep transit is detected with a signal-to-noise of 26. The middle panel shows the same HATNet and WHAT data with the transit zoomed-in and binned with $\phi = 0.0005$ bin-size. The lower panel exhibits the Sloan $z$-band photometry follow-up taken by the FLWO 1.2 m telescope. Overplotted is our best (Mandel & Agol 2002) fit.
Gliese 436: $R=3.8 \, R_{\text{Earth}}, \, M=23 \, M_{\text{Earth}}$
Follow-Up Spectroscopy

• Initial reconnaissance spectroscopy
  – Identify stellar imposters
  – Characterize host star
    • CfA Digital Speedometers
    • New fiber-fed TRES instrument at FLWO

• Precise radial velocities for orbits/masses
  – HIRES, HET, HARPS-North
Reconnaissance Spectroscopy

• SAO Instruments
  – CfA Digital Speedometers (1978-2007)
  – TRES fiber-fed echelle (2007-)

• Success rate
  – 540 candidates: Vulcan, TrES, HAT, KELT
  – 4031 spectra so far
  – 8 confirmed transiting planets
  – A few more coming
Pushing to Lower Masses

- Keck 10-m with HIRES: 1 to 2 m/s
  - 1 m/s projected to require 2.5 hours at $V=12$
- ESO 3.6-m with HARPS: 20 to 50 cm/s
  - 1 m/s requires 1 hour at $V=12$
  - Located in Chile
Achieving better than 1 m/s: Stability & Simultaneous ThAr reference

\( \Delta RV = 1 \text{ m/s} \)

\( \Delta \lambda = 0.00001 \text{ A} \)

15 nm

1/1000 pixel

\( \Delta T = 0.01 \text{ K} \)

\( \Delta p = 0.01 \text{ mBar} \)

Vacuum operation

Temperature control
New Earths – HARPS North

• Collaboration with Geneva
• Ready for Kepler follow-up in 2009
• ~100 nights/year goal; MOU for WHT
Origins of Life in the Universe
Initiative at Harvard

- Formally approved with funding profile, May 2006
- Synergy between 5 areas at Harvard, 3 new facilities
- Pre-biotic Chemistry
- Extraterrestrial Samples
- New Earths
- Led by Dimitar Sasselov
Other Initiatives

• All-sky survey from space
  – Smaller planets than ground-based surveys
  – Complements Kepler
  – Finds brighter targets, allows better follow-up

• Giant Telescope, Super HARPS
  – Push Doppler precision to the limit
The Legacy of Kepler

• Frequency/characteristics of rocky planets
  – Mass, radius, density, orbital distributions
  – Host star characteristics
  – Information for the design of future missions
Legacy of All-Sky Survey

• The brightest and nearest transiting planets
  – Best targets for follow-up studies for years to come
Transiting Exoplanet Survey Satellite

MIT: Instrument, operations
CfA: Optics, Science Center
Ames: Spacecraft, launch

All-sky survey in 2 years
Neptunes, evenEarths
Periods up to 2 months
$10^6$ targets, $\sim10^3$ planets
University-style experiment
TESS Scientific Goals

• Survey 100% of the sky
  – Discover >1000 bright nearby transiting exoplanets
  – Period coverage up to 60 days
  – Planet size coverage down to super earths
    ‣ Emphasize cool dwarf host stars

• Finish the survey by 2013
  ‣ Follow up most interesting planets with HARPS (N&S)
  ‣ Provide targets for JWST (launch in 2013)
Targets for TESS Searches

• Solar-type (G+K) Stars:
  \( \sim 10^6 \) brighter than \( I = +12 \)

• M Dwarfs:
  \( \sim 10,000 \) within 30 pc
Mockup of TESS Camera Array
CCDs Selected for TESS

MIT Lincoln Lab 4Kx4K, 15 μ pixels, 144 Mpixels total
Frame transfer in 5 ms, Flight proven on HETE 2
Low-power hybrid electronics
M Dwarf Spectra & TESS Passband

GL 411
M2
V-I = 2.1
$m_I = 5.3$
d = 2.54 pc

GL 213
M4
V-I = 2.8
$m_I = 8.7$
d = 5.87 pc

GL 406
M6
V-I = 4.0
$m_I = 9.5$
d = 2.39 pc

GL 752B
M8
V-I = 4.3
$m_I = 12.8$
d = 5.85 pc

Spectra: Brett ‘95  Magnitudes: Bessell ‘91
TESS Spacecraft (NASA Ames)
HETE-2 Satellite:
“Alpha Version for TESS”

- Developed, integrated, tested on-campus at MIT
- Reliable, low cost system ($7M spacecraft + $18M launch)
- Launched October 2000; in operation 6+ years for GRB searches
- Low earth orbit (600 km); low inclination (i = 2 degrees)
Dedicated TESS Network (extant from HETE-2)

- *<i> i < 2° orbit: radiation damage 1000 times lower than for i = 28° orbit*
- *Three S-band stations along equator (+ one additional)*
- *Can achieve 15 Gb/day (since 4 x 15 = 60 passes per day)*

- Cayenne: SupAero (France)
- Singapore: RIKEN-Japan
- Kwajalein: MIT Kavli Institute
- Malindi (New station; Italy)
TESS Status

• Seeking private funds (MIT and CfA)
• Seed money allocated
  – Hardware preliminary design underway
  – Lab test of prototype camera underway