Future Space and Ground Astronomical Capabilities for Searching for Life on Exoplanets

Meadows, 2017
(Credit: Hasler, Meadows, & Domagal-Goldman)
Ground Based Extremely Large Telescopes

- Two advantages of ELTs over space telescopes
  - Aperture:
    - 25 m (Giant Magellan Telescope)
    - 30 m (Thirty Meter Telescope),
    - 39 m (European Extremely Large Telescope)
  = spatial resolution and collecting power
- High Resolution Spectroscopy ($\lambda/\Delta\lambda \sim 100,000$) = line shifts / kinematics
1. Exoplanets in Transit

- $O_2$ (Snellen et al. 2013, Rodler & Lopez-Morales 2014)
- Advantages to M stars (over Solar-type)
  - Higher transit signal because $R_{\text{planet}}/R_*$ is larger
  - Higher transit probability because Habitable Zone is closer in
  - Higher transit frequency because Habitable Zone is closer in
- Doppler shift is key – takes exoplanet’s spectral lines away from Earth’s telluric lines

Rodler & Lopez-Morales 2014
Simulation of Snellen 2013

30 transits at 3 / yr → 10 years
Multiply by ~1.5 to account for red noise

Bottom line: For an Earth-like planet around an M4 (M6) star at 5 pc, we need 60 (84) transits; that will take 12 (25) years to accumulate.
Getting Abundances from Cross-Correlations

Forward model: Depends on P-T profile and volumetric mixing ratios
Mixing ratio is probably a lower limit

- Higher pressure lines are broader = harder to detect
- Clouds block some layers
- Refraction can block lines from small scale heights

Hot Jupiter HD 179949b: Brogi et al. 2014
Exoplanets in Transit: Other Biomarkers

- H$_2$O, CH$_4$, CO, CO$_2$ all have near-infrared absorption lines
- CO and sometimes H$_2$O detected in transiting and non-transiting hot jupiters:
  - HD 209458 (Snellen 2010),
  - τ Boo (Brogi 2012, Rodler 2012),
  - 51 Peg (Brogi 2013, Birkby 2017),
  - HD 189733 (de Kok 2013, Brogi 2013),
  - HD 179949 (Brogi 2014)
- Harder than O$_2$ due to extra telluric absorption
2. High Resolution Spectroscopy + High Contrast Imaging

- Proxima b sits 0.05 AU from its star at 1.3 pc = 38 mas
- Inner working angle > $2\lambda/D$
  - $D$  \hspace{1em} $2\lambda/D$ at 760 nm and 2.2 $\mu$m
  - 10m \hspace{1em} 32mas \hspace{2em} 91 mas
  - 25m \hspace{1em} 12 mas \hspace{2em} 36 mas
  - 39m \hspace{1em} 8 mas \hspace{2em} 23 mas
    - It’s very hard to work closer than 2-3 $\lambda/D$
- For a Solar Type Star, 1 AU is at $2\lambda/D$ at 83 pc
Combining coronagraphy and spectroscopy

$10^5$ contrast coronagraph $\times$ $10^3$ contrast spectroscopy

Advantage: non-transiting planets!

Morzinski et al. 2015

Snellen 2015
Easiest: Broad-Band Albedo

Look for the reflected spectral lines of the star, Doppler shifted from the planet

Signal $\propto \sqrt{N_{\text{lines}}}$
Simulated Yield of Albedo Measurements

All of these are known planets

Sample program: 28 nights

Current AO technology: 62 planets
15 with $R < 1.6 \, R_{\text{Earth}}$
20 in habitable zone with $R < 4 \, R_{\text{Earth}}$

Advanced control: 146 planets

Proxima b

Males et al. 2018, SPIE
Next step: Same idea, but carve up spectral space

Lovis et al. 2017 comparison of spectrum with (black) and without $O_2$ (red) in 60 nights (3 years) of observation. 3.6σ detection.
Ground Based ELTs…

- Detection of molecules in transiting and non-transiting planets possible
- Detection of albedos of a large number of known planets possible
Some quick summaries of anticipated space capabilities
HabEx – a 4m off-axis monolithic mirror space telescope

Survey ~120 stars within 10 pc multiple times at 10^{-10} contrast

HabEx shall combine the strengths of two diametrically opposed starlight suppression systems:

- **Internal CORONAGRAPH**
  - Very nimble
  - Searches for planets around many stars
  - Takes images at multiple visits to measure orbits

- **External STARSHADE**
  - Very “photon” efficient
  - Accesses closer-in planets at a given $\lambda$
  - Takes broad spectra of all planets found in ~50-100 most interesting systems
92 rocky planets
Incl. 12 HZ exo-earths

116 sub-Neptunes

65 Neptunes and Jupiter analogs
LUVOIR – Large UV / Optical / Infrared Surveyor – a 15 m telescope

Observational challenge

Faint planets next to bright stars

Extreme Coronagraph for LIving Planetary Systems (ECLIPS)

Contrast $< 10^{-10}$

Low resolution imaging spectroscopy

Bandpass: 0.2 $\mu$m to 2.0 $\mu$m

Tech development via WFIRST coronagraph
Simulation of Earth on 15 m LUVOIR

Distance = 10 pc
D_{telescope} = 15-m
T_{telescope} = 270 K
R = 150
Time = 96 hrs per band

Credit: T. Robinson / G. Arney
ExoEarth candidates vs. aperture

Stark et al. (2014)
ExoEarth candidates vs. aperture

If frequency of habitable conditions is 10%, need 30 candidates to guarantee seeing one true exoEarth (at 95% confidence)

Stark et al. (2014)
The Origins Space Telescope (OST)
From First Stars to Life
Margaret Meixner, Community co-chair for OST, STScI/JHU/NASA Goddard
Jonathan Fortney, Exoplanet co-chair for OST, UC Santa Cruz
Opacities in the Mid-IR

- A host of important molecular features for cool planetary atmospheres
- Extremely broad wavelength coverage to provide critical atmospheric context
Transmission Spectra

- Molecular detections at the atmospheric terminator
- Pressure level of any opaque clouds
- Long wavelengths may allow for seeing through the clouds, depending on particle size, yielding additional cloud constraints
- Spectral resolution of MISC + concurrent ground-based monitoring + long wavelengths will mitigate effects of inhomogeneous stellar photosphere (Rackham et al., 2018) on H$_2$O features
Timeline

ELTs First Light – 2024-2027ish

HABEX, LUVOIR, OST: 2035 and beyond