Characterizing Habitable Worlds...

From the Moon

Margaret Turnbull - STScI / Carnegie
Preamble:

The moon is OK for astronomy, but not necessarily better than space.

Challenges are present (dust, radiation, thermal fluctuations) but surmountable.

If we go to the moon, it will NOT be so that we can do science. Scientists are trying to cooperate.

QUESTION: Are there any astrophysics projects that are uniquely enabled by the lunar platform?
Characterizing Habitable Worlds Around Nearby Stars

- How common are they?
- How old are they?
- Where are they?
- Are they inhabited?
- Can we go there?
The Terrestrial Planet Finder

The technology driver is the need to suppress starlight by a factor of 1 million (at mid-IR wavelengths) or 10 billion (at optical wavelengths) at milliarcsec from the star... **this probably requires a space, not lunar-based, mission.**
New Worlds Observatory

The technology driver is the need to suppress starlight by a factor of 1 million (at mid-IR wavelengths) or 10 billion (at optical wavelengths) at small angles from the star...

http://newworlds.colorado.edu/starshade/

(ripped off from a talk by Webster Cash)
Binary Shape
Before this can happen, We have to understand:

-what does a habitable planet look like, in the **spatially unresolved** case?

-how can we probe its surface, atmosphere, and life forms given a **spatially unresolved** signal?

=> TPF precursor science begins at home...
The Thermal Earth

3-4m x 3-4

6.5-17 μm

10^{-6}

starlight

suppression

TPF-I

TPF-C

H₂O

O₃

CO₂

Venus

Earth

Mars

Brightness Temperature, K

Wavelength (μm)

Intensity

Wavelength (μm)
The “Optical” Earth.

Woolf et al. (2002) and Turnbull et al. (2006): Earthshine

=> Spatially unresolved signal (like exoplanet observations).
The “Optical” Earth.

Terrile et al. 2007: Degeneracies!!
The “Optical” Earth.
The “Optical” Earth.
The “Optical” Earth.

Change over time.

This is the key to characterizing exoplanets via spatially unresolved signals.
The Variable Earth.

Photometric changes ~ 30% (Ford, Seager & Turner 2003)

“Color” of planet changes with rotation, seasons

NOTE: This is not what CERES sees.
The Variable Earth.

Red edge variations
~30% (or less?)
(Tinetti et al 2006)

O₂ variations
+/-20%

H₂O variations
+/-70%

Rayleigh scattering
+/-10%

(no clouds)

(Traub et al. LSSO)
The **Variable Earth.**
*(Tables from Traub et al. LSSO proposal)*

### Table 2. Expected Spectrum Dynamics

<table>
<thead>
<tr>
<th>Physical Element</th>
<th>Observable</th>
<th>Estimated Time Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Relative intensity in continuum</td>
<td>±20% daily</td>
</tr>
<tr>
<td>Clouds</td>
<td>Overall brightness</td>
<td>±20% daily, ±10% annual</td>
</tr>
<tr>
<td>Oxygen &amp; clouds: cloud cover type</td>
<td>Variations in O₂ signal (0.76 µm)</td>
<td>±20% of O₂ signal</td>
</tr>
<tr>
<td>Water &amp; clouds: cloud cover type</td>
<td>Variation in H₂O signal (0.93 µm)</td>
<td>±70% of H₂O signal</td>
</tr>
<tr>
<td>Biomarkers &amp; habitability</td>
<td>O₂, O₃, H₂O, and cloud variability</td>
<td>See above</td>
</tr>
<tr>
<td>Continents &amp; oceans</td>
<td>Periodic shifts in albedo level.</td>
<td>±20% weekly</td>
</tr>
<tr>
<td>Atmospheric mass above clouds</td>
<td>Rayleigh scattering in blue</td>
<td>±10% daily</td>
</tr>
<tr>
<td>Red edge of land plants</td>
<td>Increased albedo for λ &gt; 0.72 µm.</td>
<td>±5% daily</td>
</tr>
</tbody>
</table>

### Table 3. Expected Albedo Flux Dynamics

<table>
<thead>
<tr>
<th>Physical Element</th>
<th>Observable</th>
<th>Estimated Time Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemisphere-to-hemisphere variations from north-south land, ocean, and ice differences</td>
<td>North and south hemisphere visible fluxes, as viewed from either pole</td>
<td>±40%</td>
</tr>
<tr>
<td>Day-to-day variations from weather</td>
<td>Day by day visible global fluxes</td>
<td>±12% daily</td>
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<tr>
<td>Month-to-month variations from seasons</td>
<td>Month by month visible global fluxes</td>
<td>±3% monthly</td>
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<tr>
<td>Year-to-year variations from multi-year weather changes</td>
<td>Year by year visible global fluxes</td>
<td>±2% yearly</td>
</tr>
</tbody>
</table>

Use spatially resolved data to validate algorithms for the **integrated** signal.
The Variable Earth.

⇒ Thermal variations ~50% (Hearty et al 2007)

(AIRS data)
The Variable Earth.

⇒ Starlight is NOT polarized, Earth surfaces ARE

⇒ Polarization variations with rotation (Stam et al 2004)
The **Variable Earth.**

⇒ Starlight is NOT polarized, Earth surfaces ARE

⇒ Polarization variations with phase (Stam et al 2004)
TPF Preparatory Science
From the Moon

(STM’s NASA “LSSO” Proposal)

See also:
Traub et al.
“REFLECT”

ALIVE: Autonomous Lunar Investigation of the Variable Earth
Characterizing Earth’s Habitability and Bio Signatures
PI: Margaret Turnbull, STScI
ALIVE:
Characterizing Terrestrial Change.

Do photometry, spectroscopy, and polarimetry of the Earth on an hourly basis for as long as possible in optical and near-IR wavelengths (possibly UV and thermal IR as well).

- Small telescope, Astronaut deployable
- Autonomously functioning after that
- Study change due to rotation, phases, seasons...solar cycles?? Want maximum possible lifetime.
ALIVE baseline

Extended Concept
ALIVE:

Use spatially resolved measurements in conjunction with models to find out:

To what extent can we characterize unknown worlds, given a spatially unresolved signal?
Location?
(From Traub et al. LSSO proposal)
ALIVE and Earth Science

The modern environmental movement was born of the Apollo missions.
ALIVE and Earth Science

Bi-directional reflectance measurements (see all phase angles from the moon)

Long term global albedo variations (moon provides a stable platform)
Clouds: Limb-to-limb cloud cover, albedo, and optical depth
=> microphysics
=> constrain Earth’s albedo and thermal emission, critical for climate models
ALIVE and Earth Science

Obtain time- and space-resolved column measurements for greenhouse gases produced by natural and anthropogenic sources ($\text{CO}_2$, $\text{SO}_2$, $\text{CO}$, $\text{CH}_4$)
Extension into the UV:
Cloud transmittance and absorption, surface UV radiation, time- and space-resolved measurements of ozone, aerosols, NO$_2$
=> also critical to understanding Earth’s energy balance
ALIVE and Earth Science

Retroreflection and “Hot spot” observations:
- spectral separation b/w ground + plants enhanced
- probe canopy structure as the earth turns
- vegetation abundance and health
Cost/benefit trades to be investigated:
-wavelength resolution reqs (R~250)
-wavelength range (UV? thermal?)
-spatial res reqs (~10km/100km)
-power (RTGs? solar? batteries?)
-location of deployment (poles?)
-thermal control, dust mitigation
-operations during lunar night?
# ALIVE Science and Design Team

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<thead>
<tr>
<th>Margaret Turnbull, P.I.</th>
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<td>Jeff Valenti</td>
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Lunar Environmentalism

“The Apollo Earth photographs, while receiving very limited formal attention...have been enormously significant in altering the shape of the contemporary geographical imagination.”
Cosgrove, 1994, AAAG
Lunar Environmentalism

-> Apollo, Earthshine, ALIVE: continuing to use the moon to learn about Earth...and beyond

-> A Lunar Base: An opportunity to learn about sustainable living

-> “Magnificent desolation”: worth preserving??
Lunar Environmentalism

Keep the moon “wild”...
Questions and comments:

-better discussion of polarization models
-mention possibility of “transit” capability, night-side sigs
-more explanation of earthshine observations for public talks
-more explanation of veg signal and why we WOULD reasonably expect such a thing to show up on other planets
-better discussion of why GEO and LEO sats are no good (note very narrow bandpasses specialized to study vegetation eg, limited spatial coverage)
-talk to someone at Goddard about dust storm silicon signature
-close with aesthetic appeal of using the Moon to learn about the Earth: Apollo, earthshine, ALIVE...also astrobiological significance of the moon
-mention aesthetic appeal of sustainable lunar base, including preservation of the “wildness” of the moon

Outline usefulness of lunar month:
-crescent through gibbous: reflectance, relevant to exoplanets
-eclipse: transmission, relevant to planet transits
-full earth: “hot spot” observations, relevant to geoclimatology