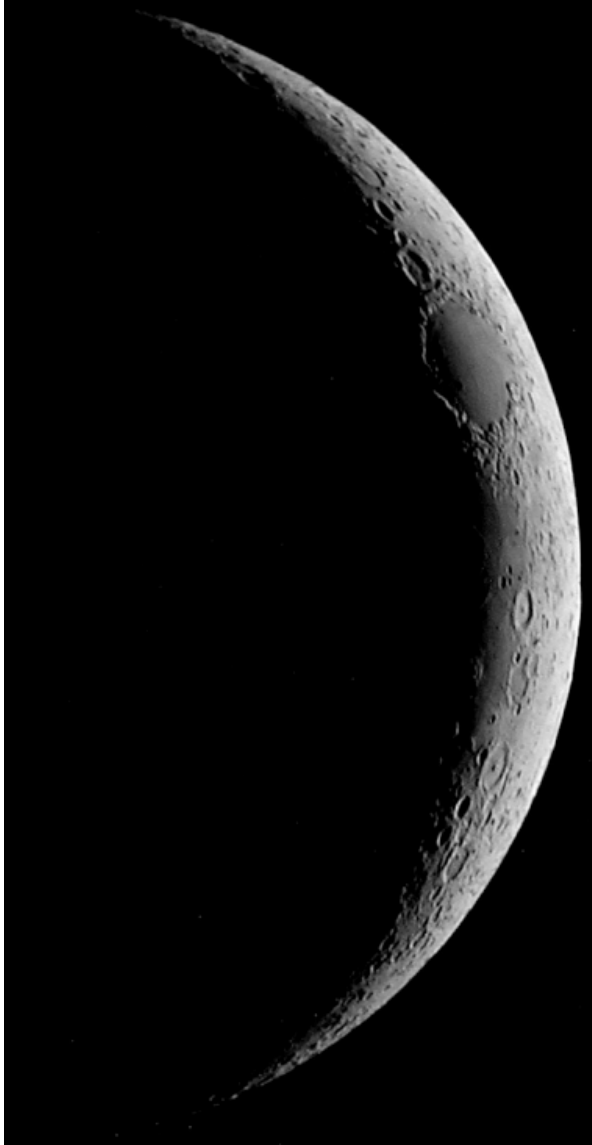
Characterizing Habitable Worlds...

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?

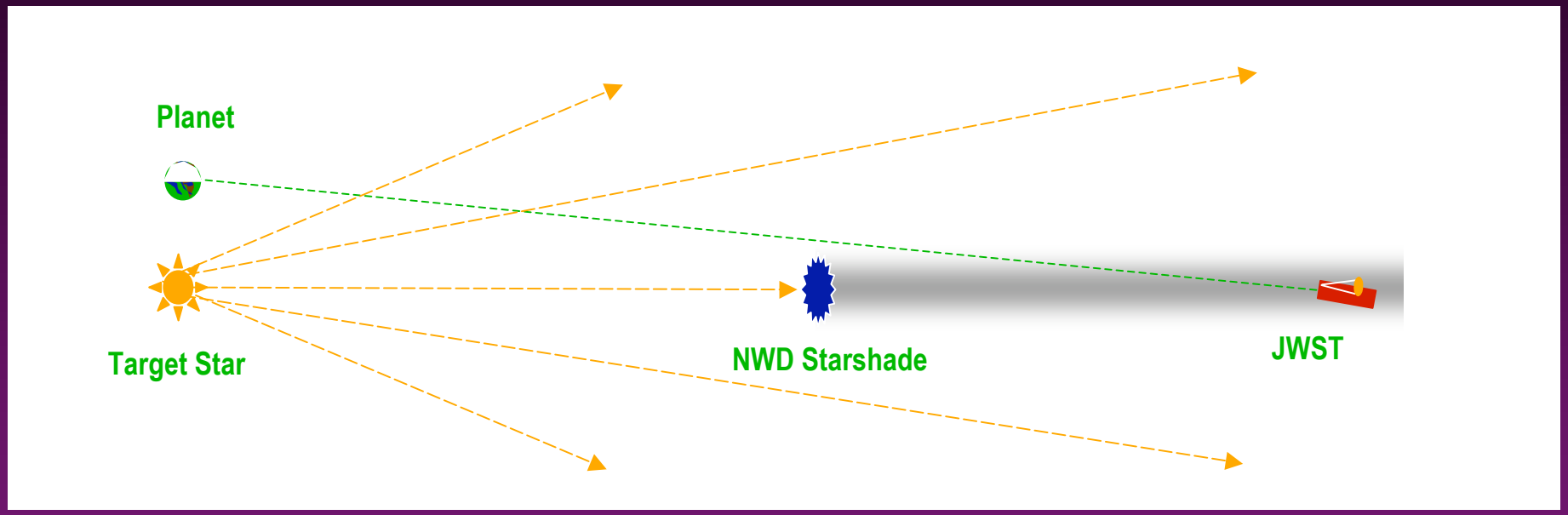
Can we go there?

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

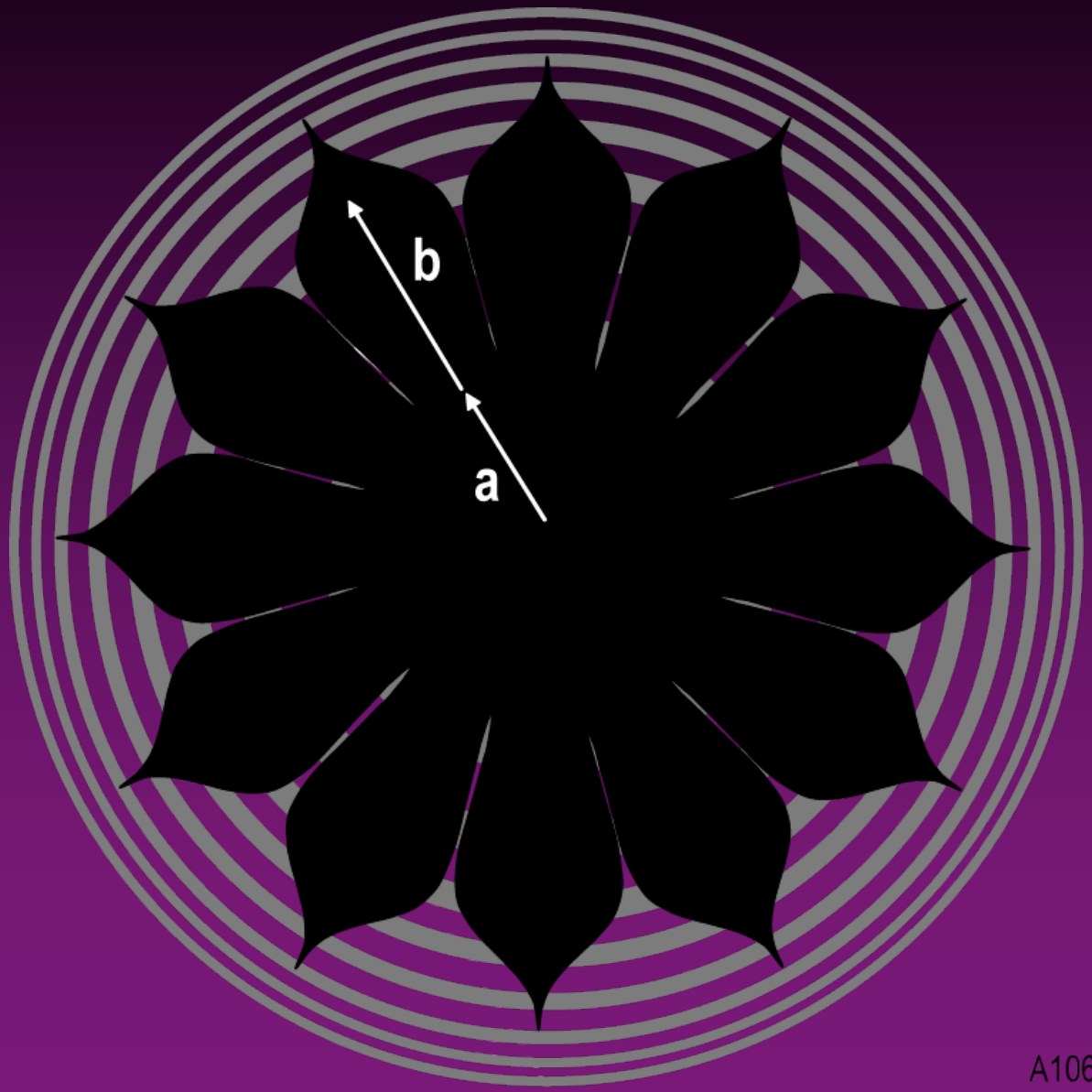
The technology driver is the need to suppress starlight by a factor of 1 million (at mid-IR wavelengths) or 10 billion (at optical wavelengths) at small angles from the star...



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

(ripped off from a talk by Webster Cash)

Binary Shape



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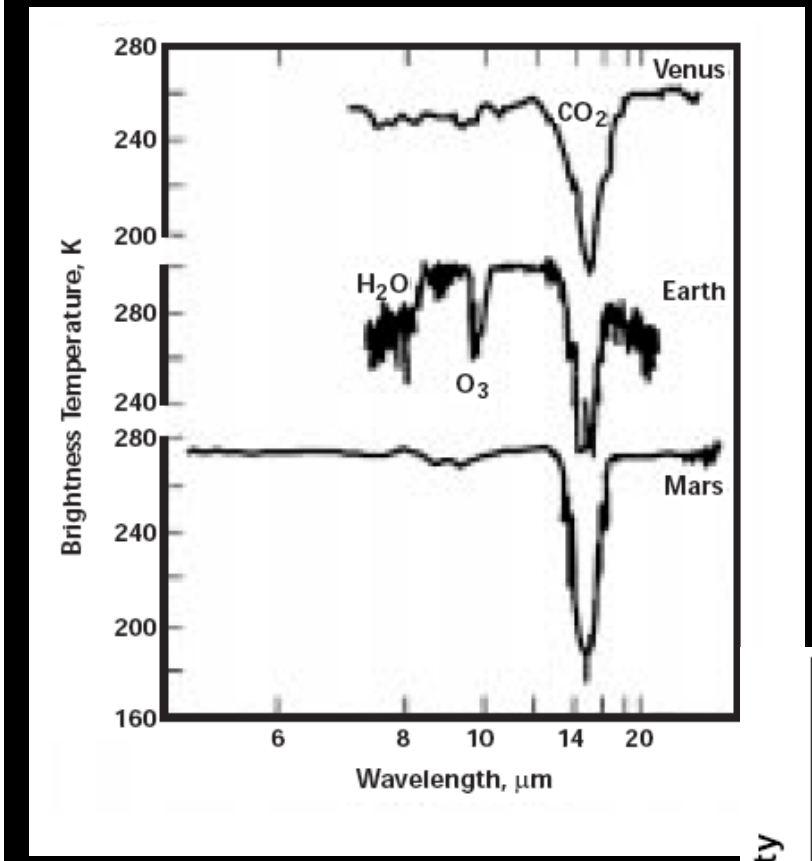
Before this can happen, We have to understand:

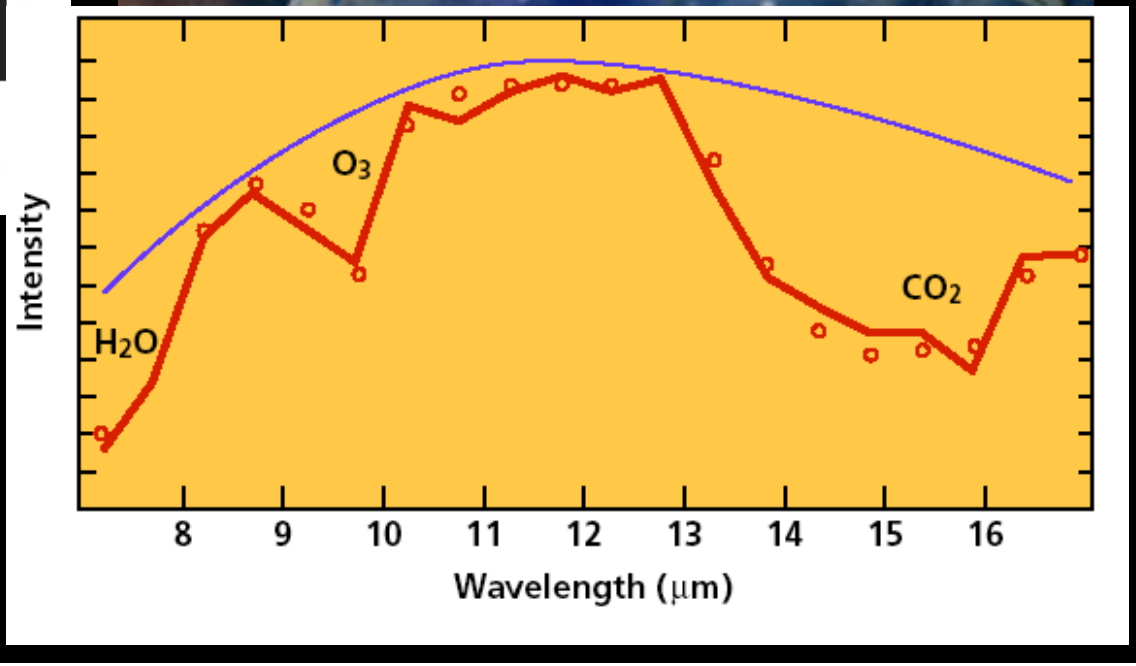
-what does a habitable planet look like, in the spatially unresolved case?

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

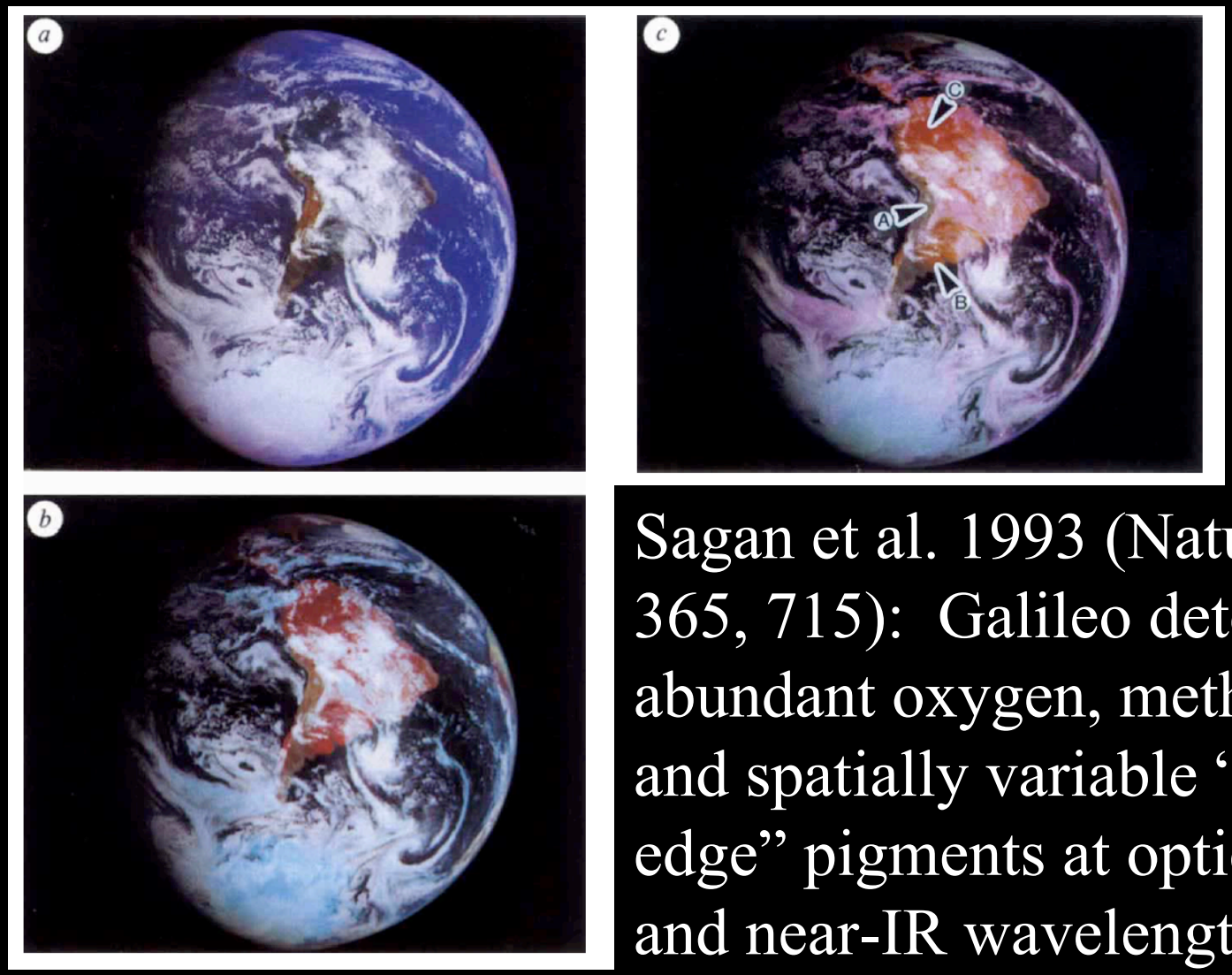
=> TPF precursor science begins at home...

The Thermal Earth





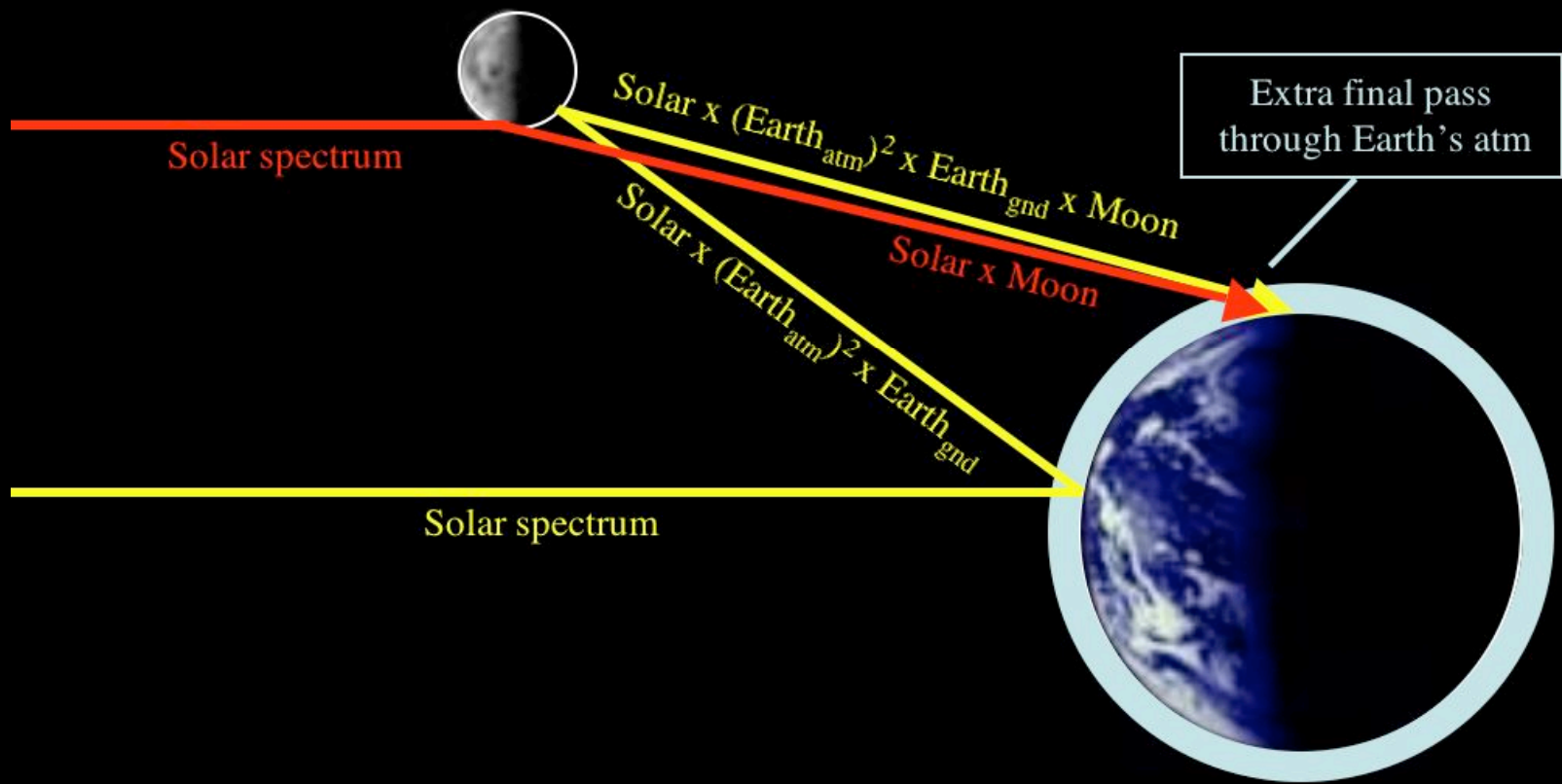
The "Optical" Earth.



Sagan et al. 1993 (Nature 365, 715): Galileo detects abundant oxygen, methane, and spatially variable "red edge" pigments at optical and near-IR wavelengths

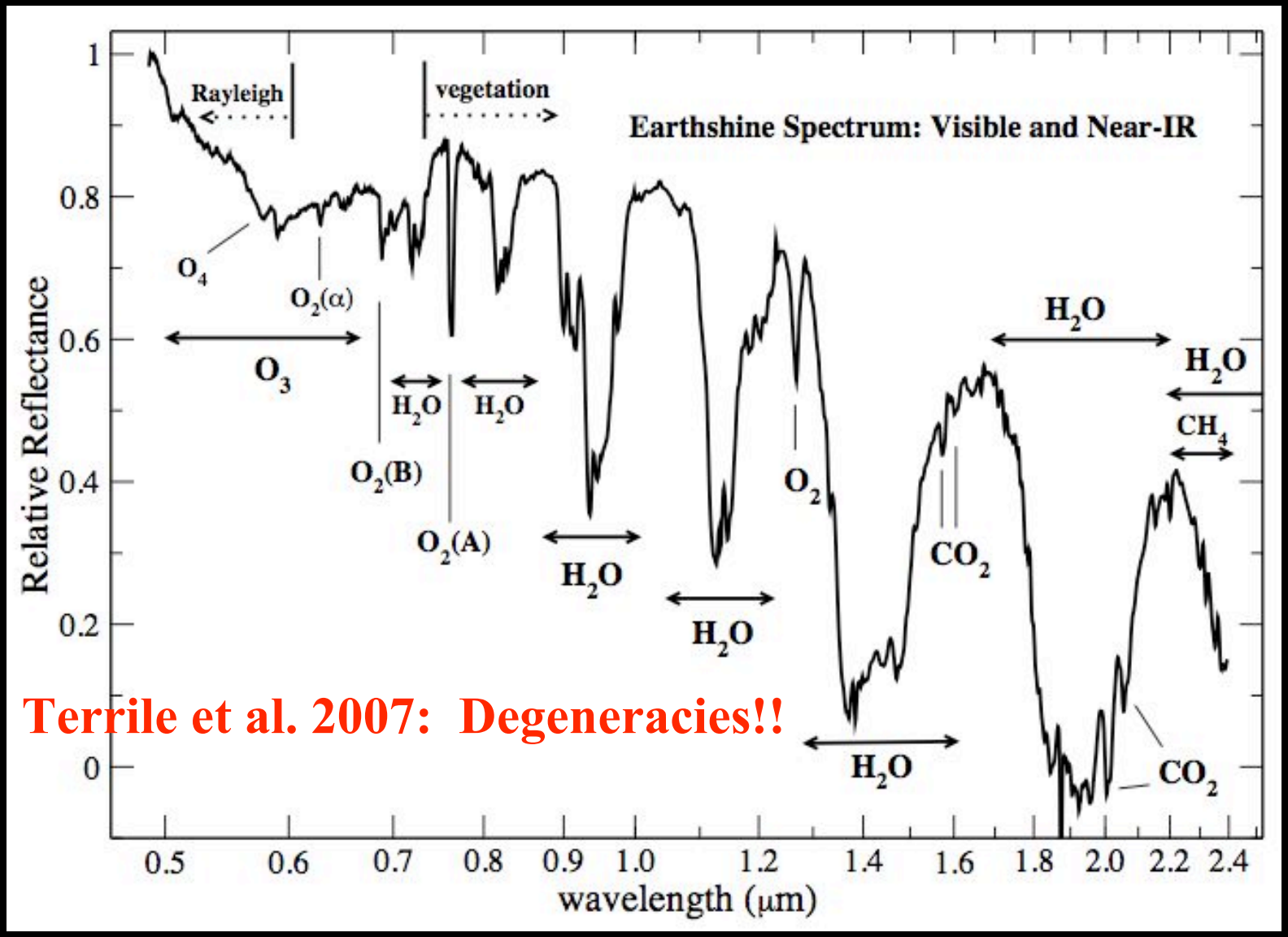
The "Optical" Earth.

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.

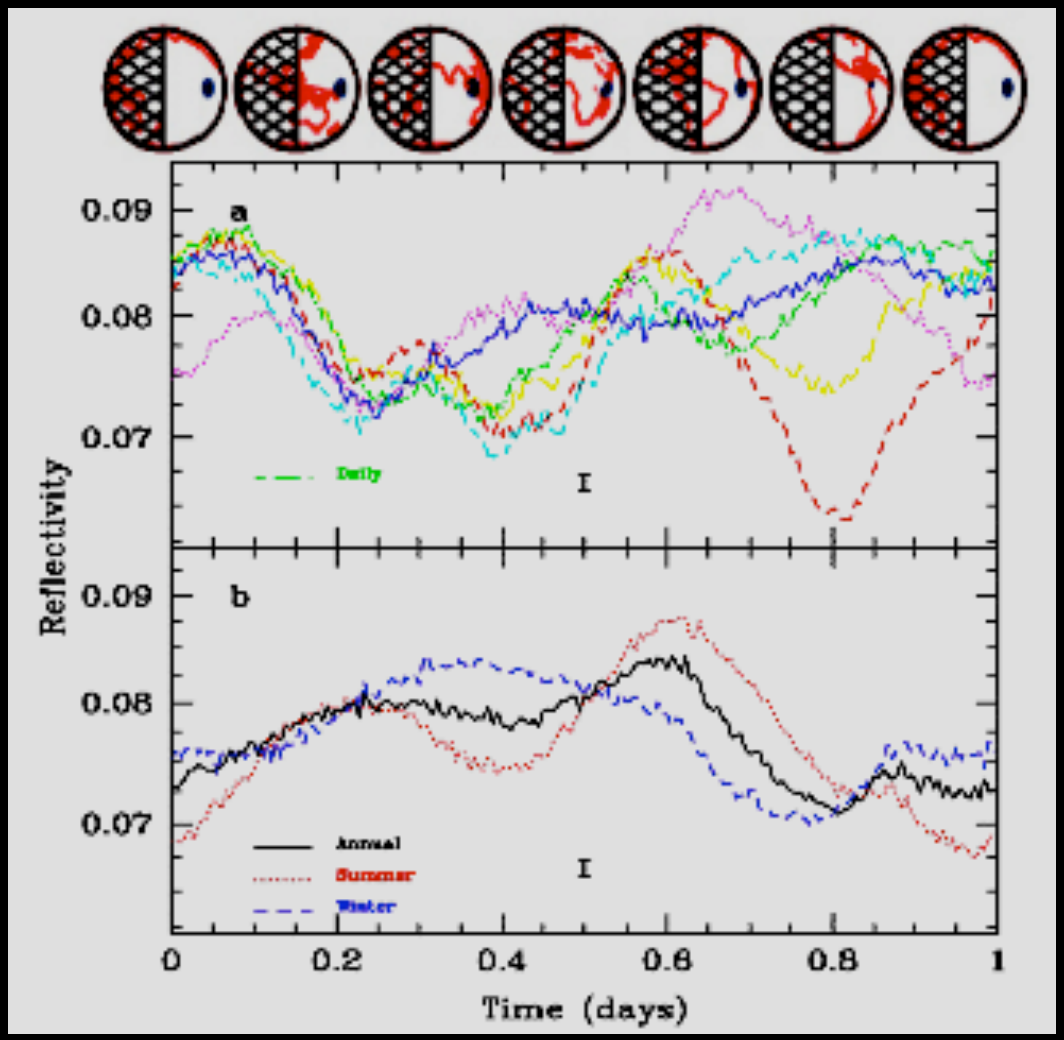
The “Optical” Earth.

The "Optical" Earth.

Change over time.

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

The Variable Earth.

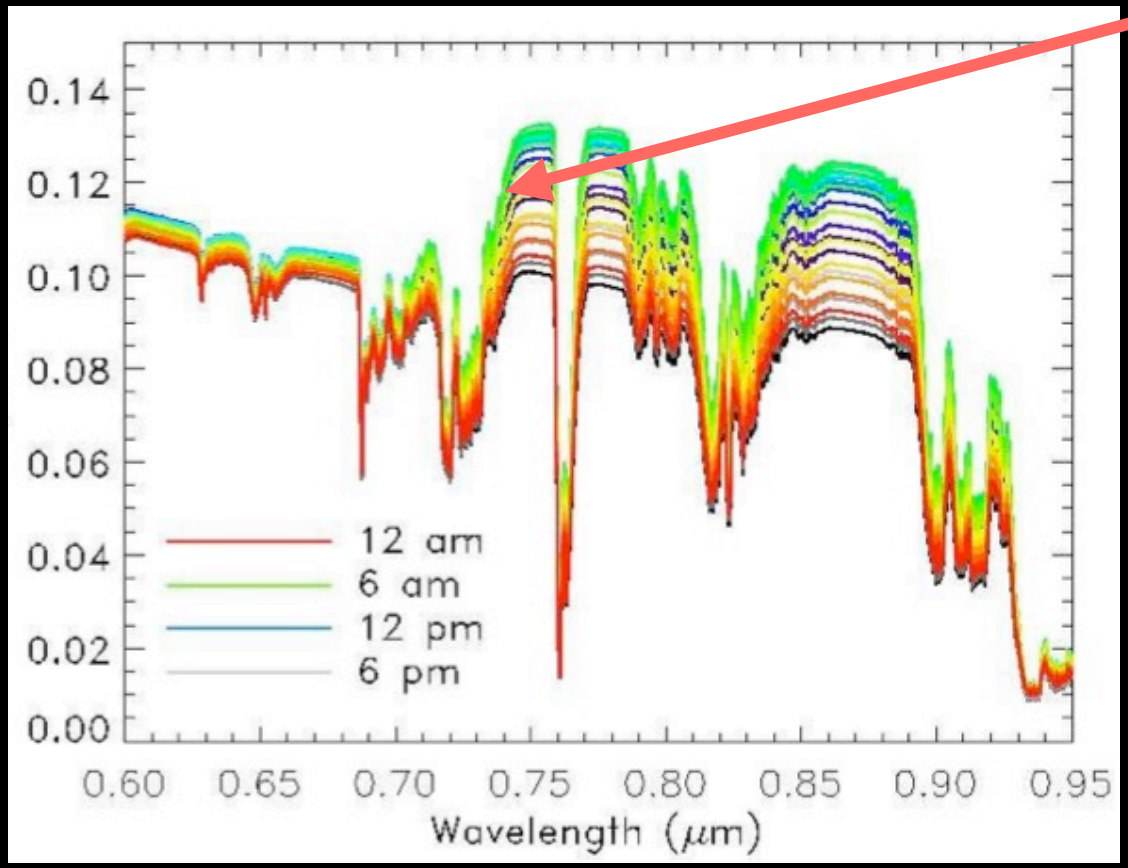


Photometric changes ~ 30% (Ford, Seager & Turner 2003)

"Color" of planet changes with rotation, seasons

NOTE: This is not what CERES sees.

The Variable Earth.



(no clouds)

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

O_2 variations
+/-20%

H_2O variations
+/-70%

Rayleigh scattering
+/-10%
(Traub et al. LSSO)

The Variable Earth.

(Tables from Traub et al. LSSO proposal)

Table 2. Expected Spectrum Dynamics

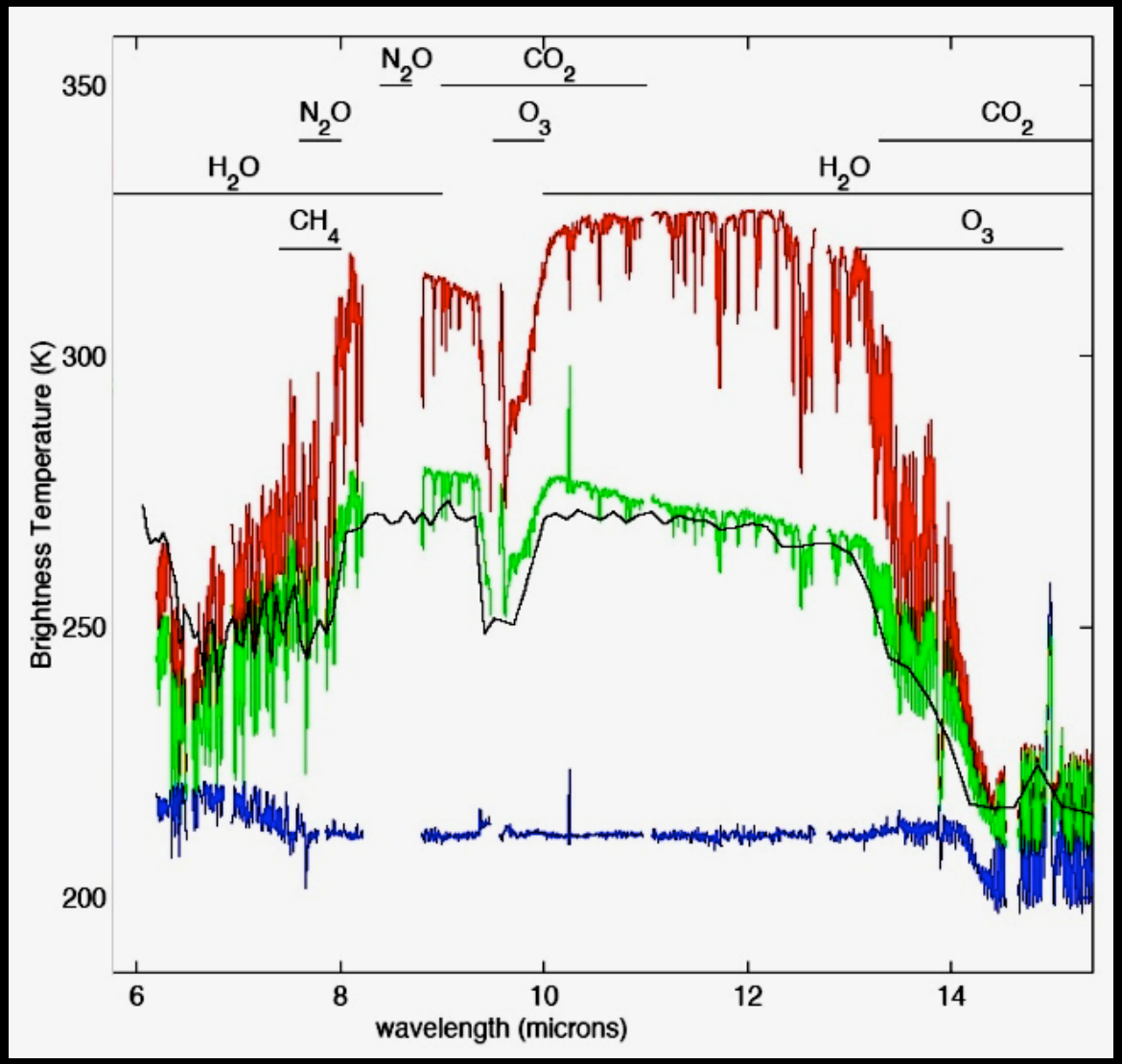
Physical Element	Observable	Estimated Time Variation
Color	Relative intensity in continuum	±20% daily
Clouds	Overall brightness	±20% daily, ±10% annual
Oxygen & clouds: cloud cover type	Variations in O_2 signal (0.76 μm)	±20% of O_2 signal
Water & clouds: cloud cover type	Variation in H_2O signal (0.93 μm)	±70% of H_2O signal
Biomarkers & habitability	O_2, O_3, H_2O, and cloud variability	See above
Continents & oceans	Periodic shifts in albedo level.	±20% weekly
Atmospheric mass above clouds	Rayleigh scattering in blue	±10% daily
Red edge of land plants	Increased albedo for $\lambda > 0.72$ μm.	±5% daily

Table 3. Expected Albedo Flux Dynamics

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

Use spatially resolved data to validate algorithms for the integrated signal.

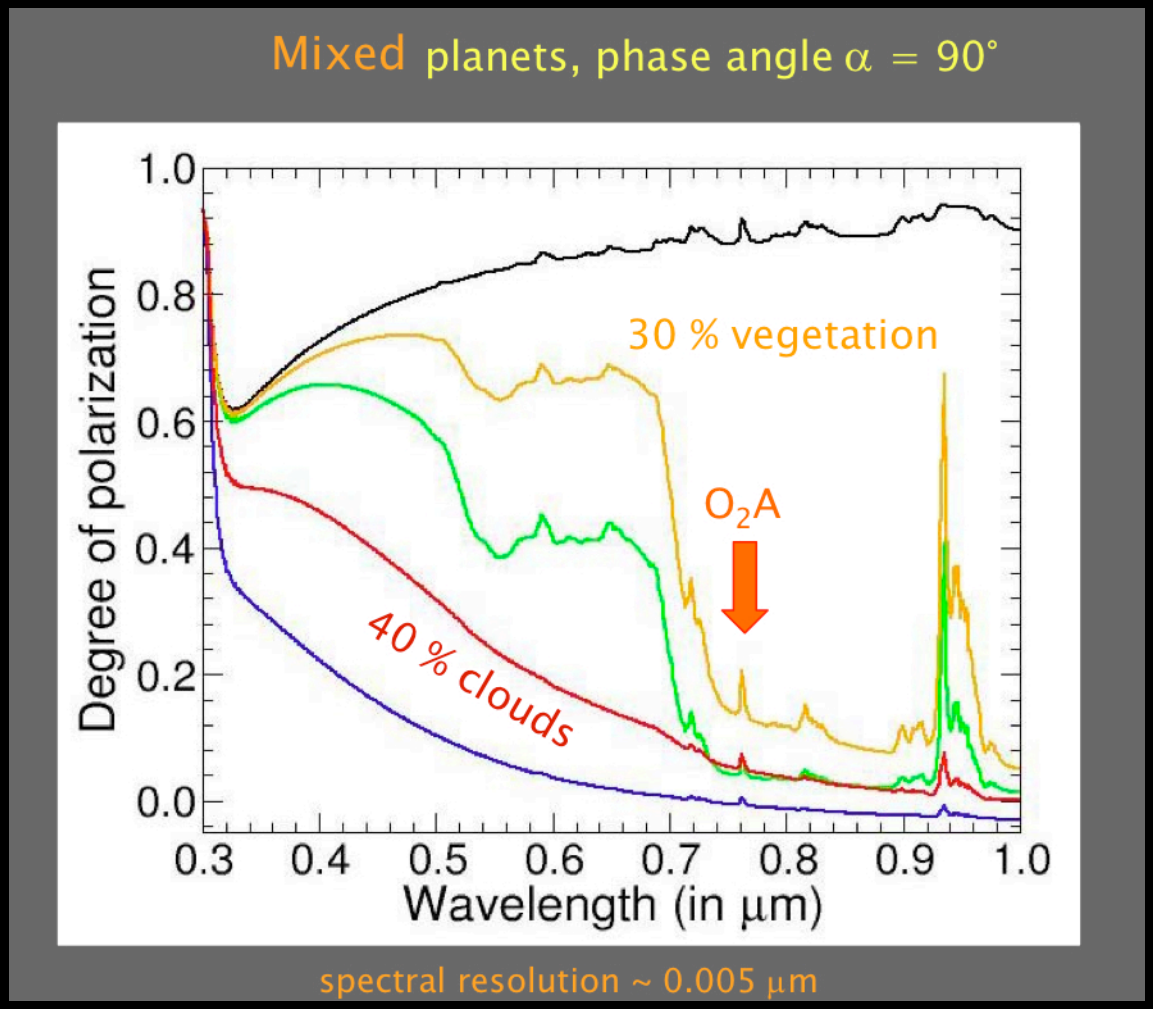
The Variable Earth.



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

(AIRS data)

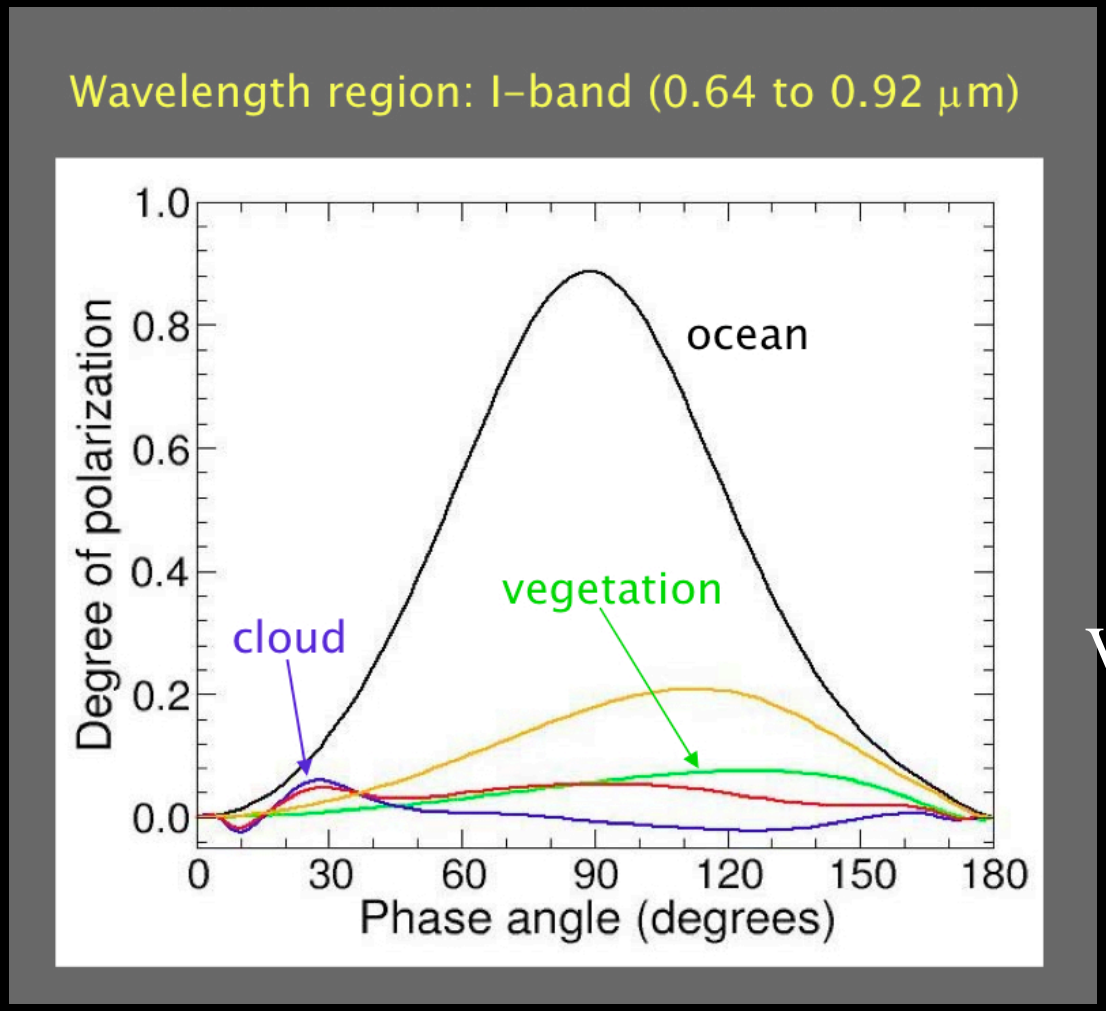
The Variable Earth.



⇒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

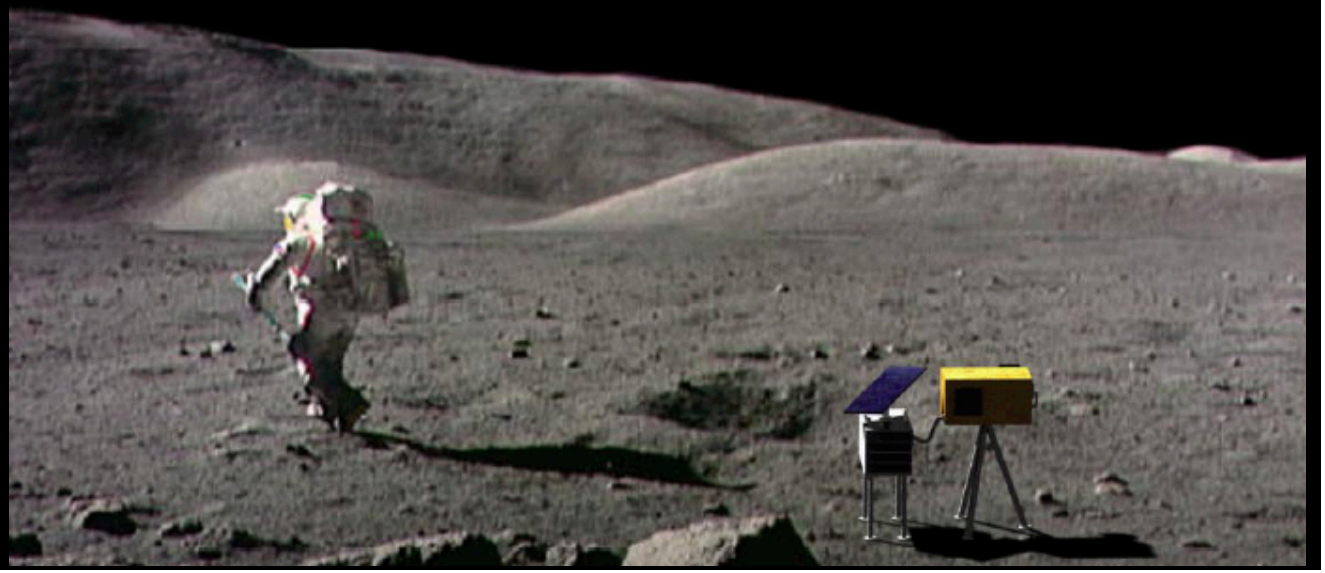
(STScI's NASA "LSSO" Proposal)

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.

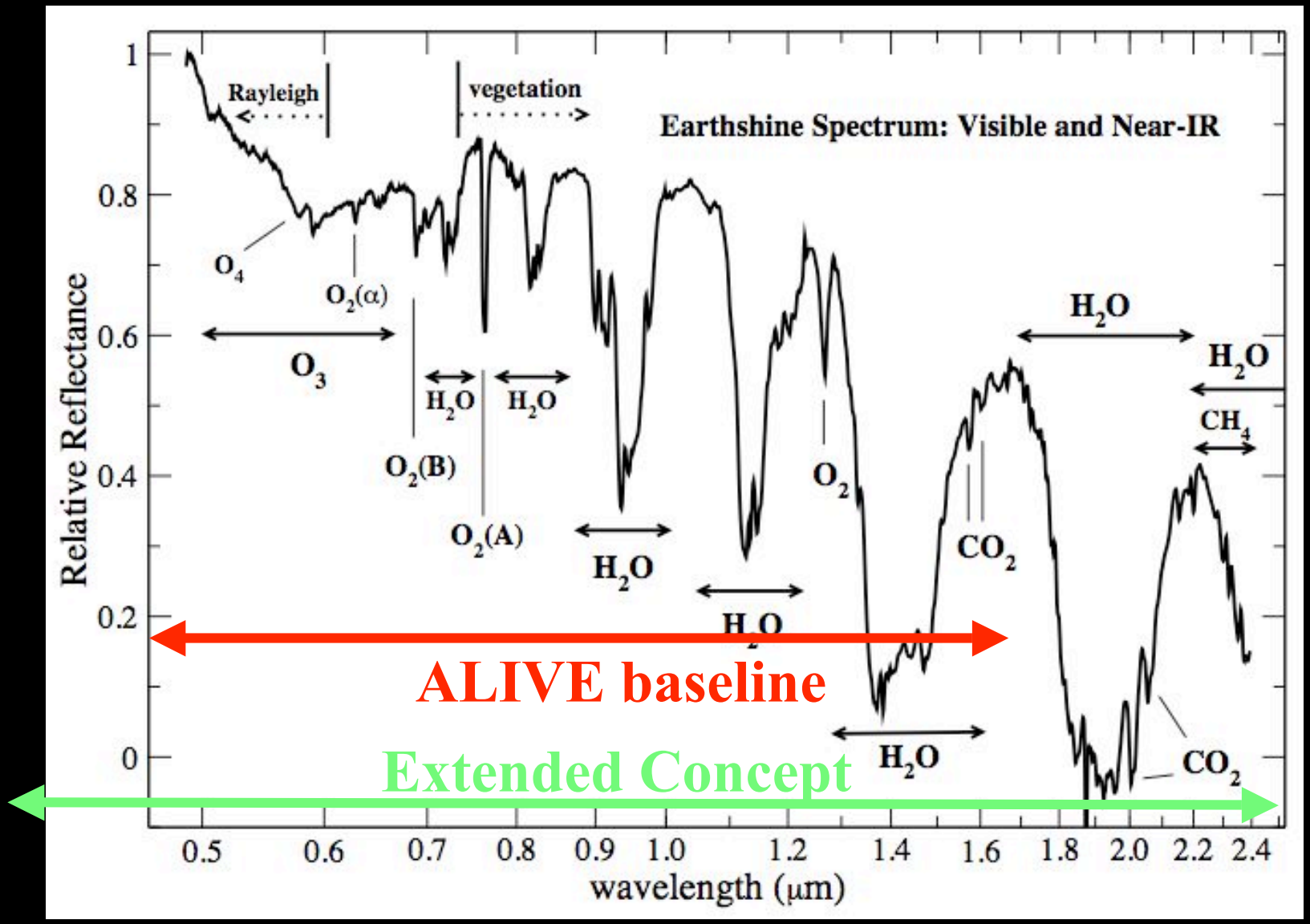
Do photometry, spectroscopy, and polarimetry of the Earth on an hourly basis for as long as possible in optical and near-IR wavelengths (possibly UV and thermal IR as well).

-Small telescope, Astronaut deployable

-Autonomously functioning after that

-Study change due to rotation, phases, seasons...solar cycles?? Want maximum possible lifetime.

ALIVE:

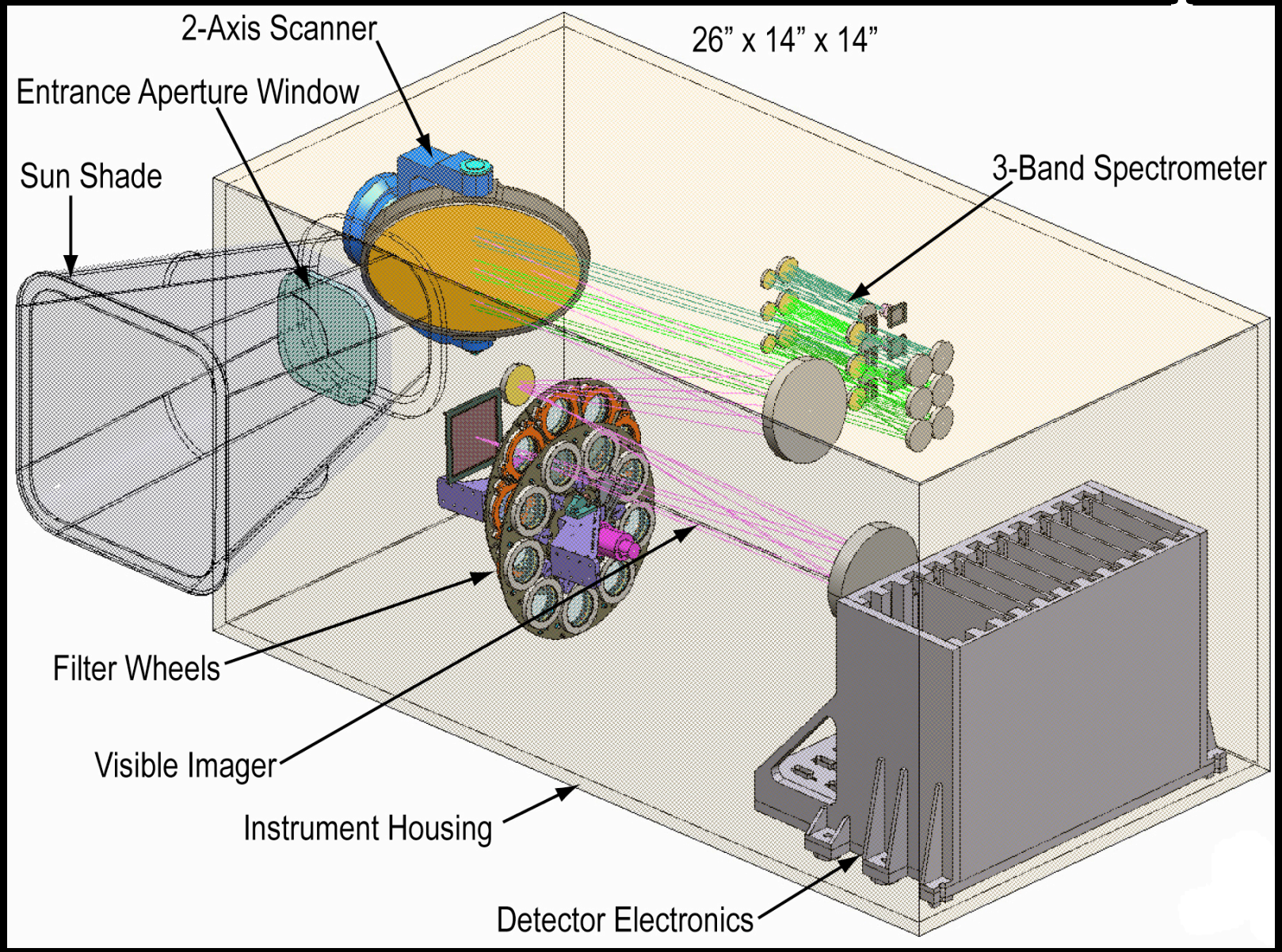

Earthshine Spectrum: Visible and Near-IR
Rayleigh
vegetation
O_4
$O_2(\alpha)$
O_3
H_2O
H_2O
$O_2(B)$
$O_2(A)$
H_2O
H_2O
O_2
H_2O
H_2O
CH_4
CO_2
H_2O
CO_2
ALIVE baseline
Extended Concept
Relative Reflectance
wavelength (μm)
0
0.2
0.4
0.6
0.8
1
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

ALIVE:

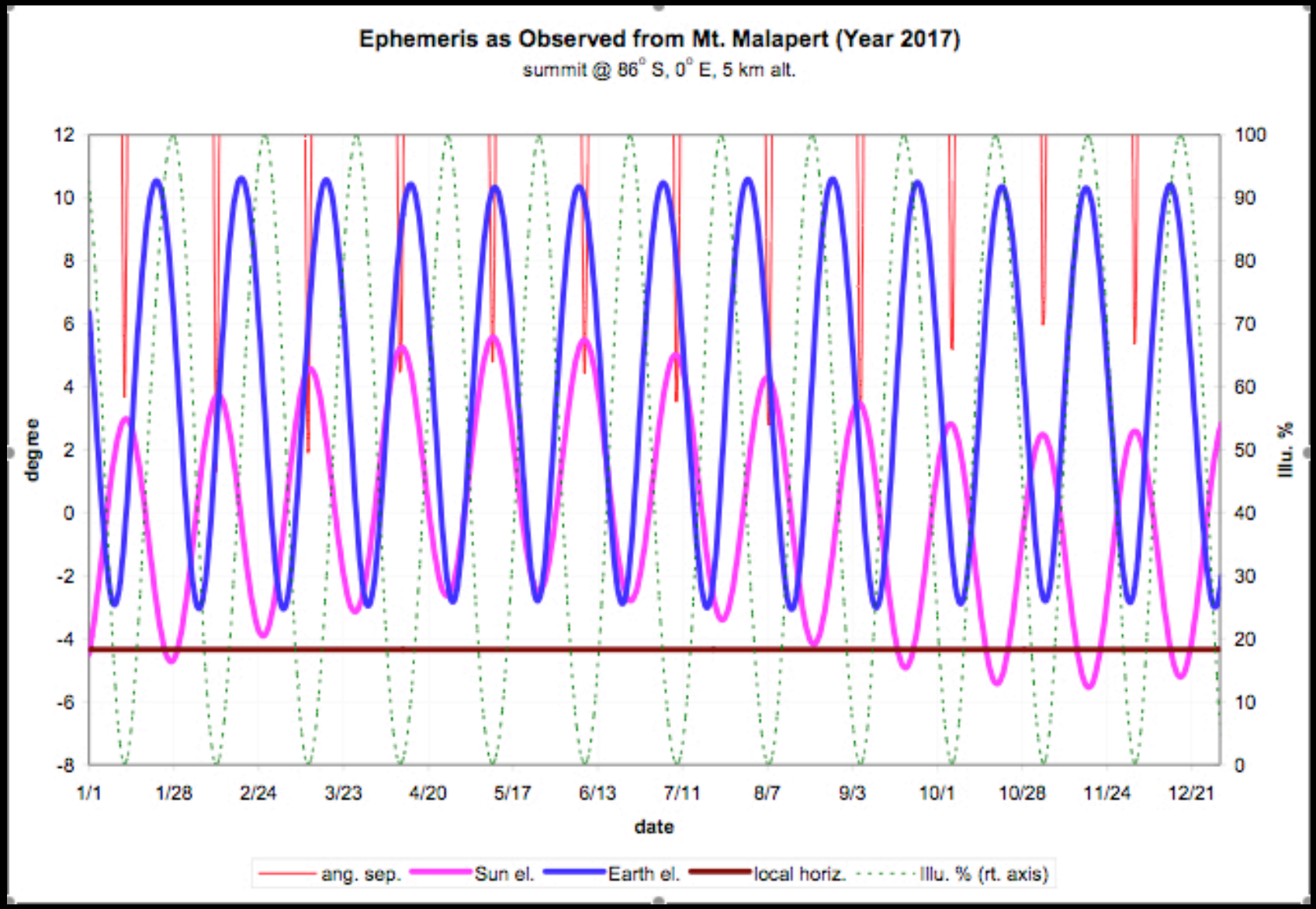
Use spatially resolved measurements in conjunction with models to find out:

To what extent can we characterize unknown worlds, given a spatially unresolved signal?

The ALIVE Instrument Concept



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)

ALIVE and Earth Science

Clouds: Limb-to-limb cloudcover, 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 (CO_2, SO_2, CO, CH_4)

ALIVE and Earth Science

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

<u>Cost/benefit trades to be investigated:</u>

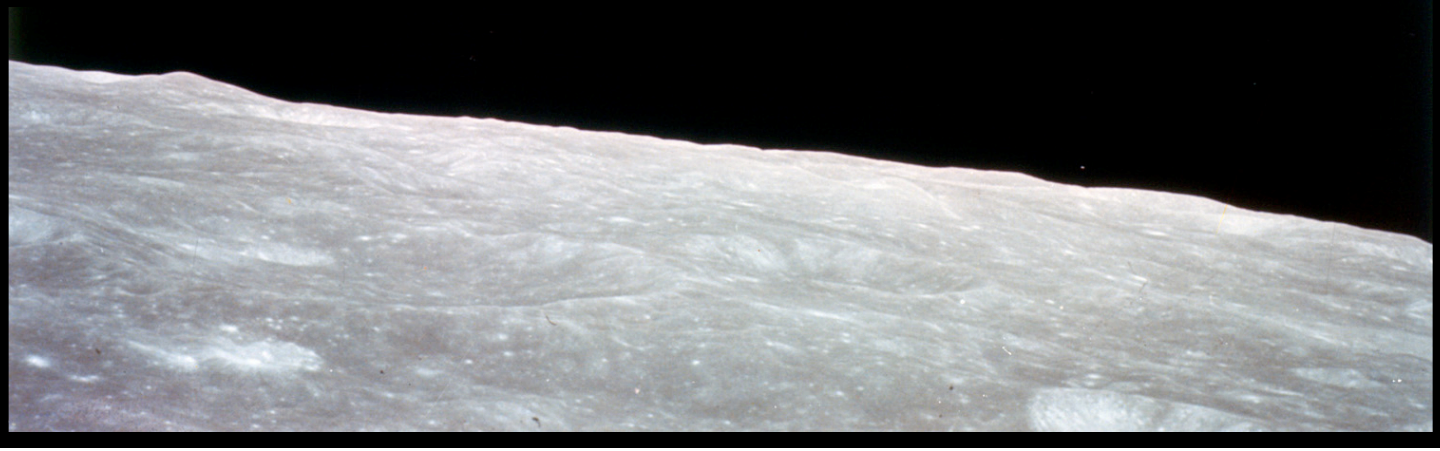
-wavelength resolution reqs (R~250)
-wavelength range (UV? thermal?)
-spatial res reqs (~10km/100km)
-power (RTGs? solar? batteries?)
-location of deployment (poles?)
-thermal control, dust mitigation
-operations during lunar night?

ALIVE Science and Design Team

Margaret Turnbull, P.I.	**Space Telescope Science Institute (STScI)/ Carnegie Institution of Washington**
Thomas Bank	Ball Aerospace
Daniela Calzetti	STScI / U. Massachusetts
Carol Christian	STScI
Mark Clampin	Goddard Space Flight Center (GSFC)
Eric Ford	Smithsonian Center for Astrophysics
Holland Ford	Johns Hopkins University
Ed Friedman	Ball Aerospace
John Grunsfeld	Johnson Space Center
Amanda S. Gulbis	Massachusetts Institute of Technology
Chuck Hardesty	Ball Aerospace
Jay Herman	GSFC
Steve Kilston	Ball Aerospace
Peter McCullough	STScI
Marc Postman	STScI
I. Neill Reid	STScI
William Sparks	STScI
Daphne Stam	Netherlands Institute for Space Research
Giovanna Tinetti	Institute d'Astrophysique de Paris
Ed Turner	Princeton University
Jeff Valenti	STScI

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

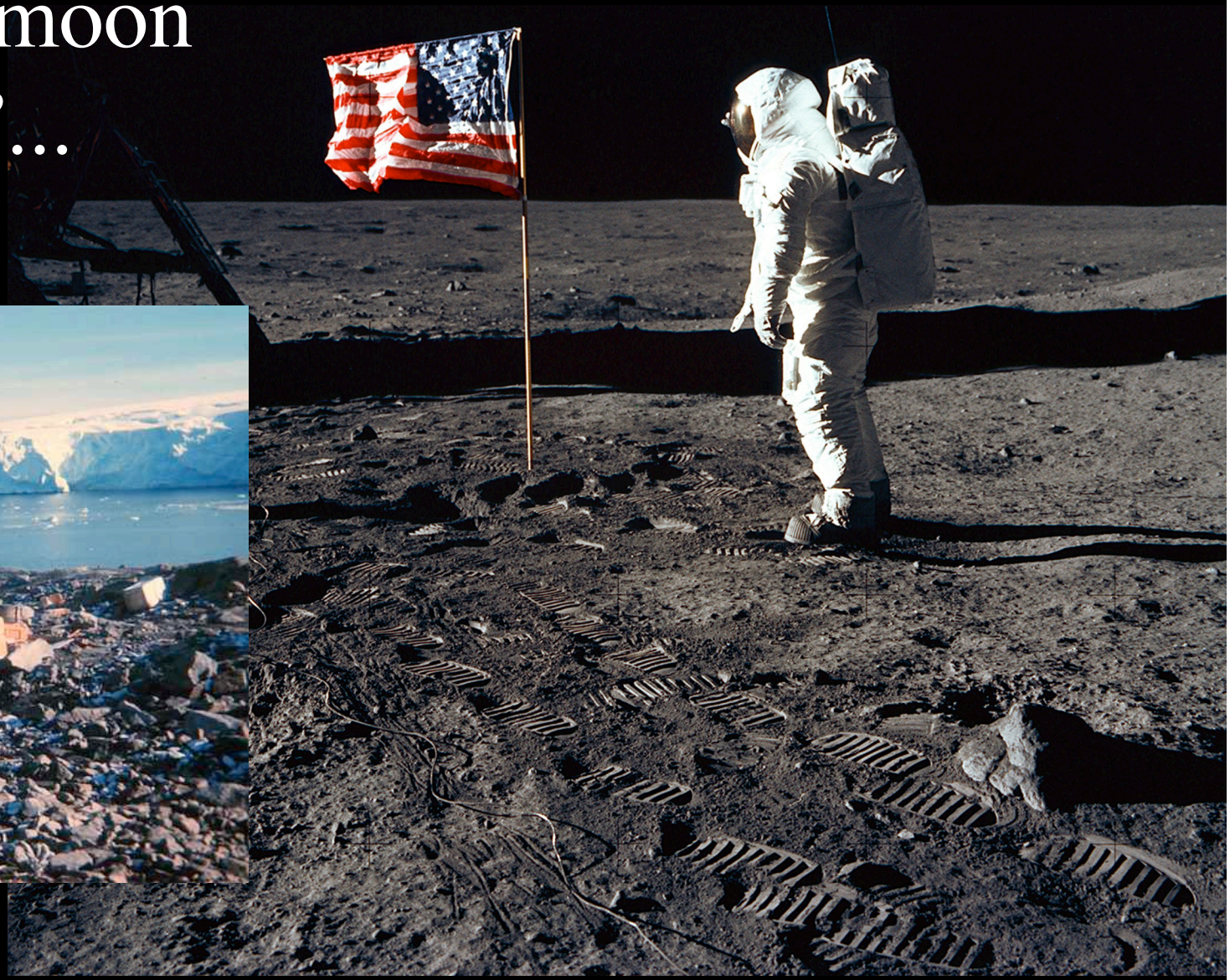
-> Apollo, Earthshine, ALIVE: continuing to use the moon to learn about Earth...*and beyond*

-> 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