AST 205. Lecture 22. December 3, 2003
Remote Sensing of Spectroscopic and Photometric Biomarkers □

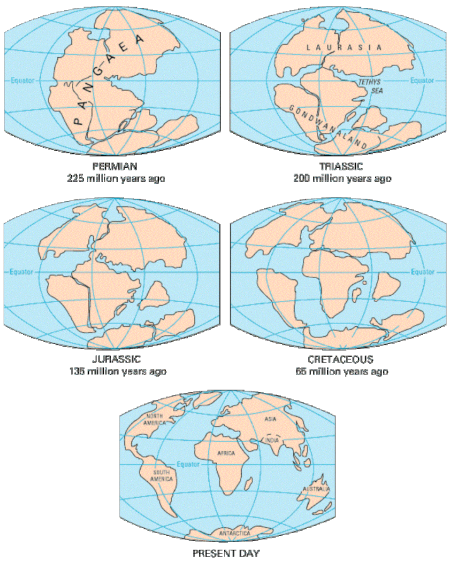
- Your homework and mine (continental drift/plate tectonics history)
- The NASA Terrestrial Planet Finder (TPF) Mission
  - Goals and Status
  - Optical/NIR and Mid/thermal-IR wavelength options
- Spectroscopic Biomarkers & Atmospheric Characterization
- Light Curve Biomarkers & Surface Characterization
- The Red Edge of Vegetation
- Observing the Earth as a Prototype Extrasolar Planet
- Beyond TPF: Life Finder and Planet Imager
- Sumamry

Assignments for week of Dec 8

- An open precept discussion on the topics listed below (individual basis, no set "teams").
- Bring a one page brief to precept outlining your views/reasoning & be prepared to discuss them.
- TOPICS: Will extraterrestrial life be found elsewhere in the Solar System? Will TPF discover terrestrial planets orbiting in the habitable zones around nearby stars? If so, will some of these planets have biomarkers detectable by TPF or other planned future facilities? Will SETI projects succeed in detecting signals broadcast by extraterrestrial civilizations in the foreseeable future?
- Problem Set 9 due in lecture on Dec 10

History of continental drift/plate tectonics ideas

- Dutch map maker Abraham Ortelius (1596) suggested that the Americas were "torn away from Europe and Africa ... by earthquakes and floods"
- German meteorologist Alfred Lothar Wegener (1912) got the timescale & reconstruction basically correct
- Princeton Prof. W. Jason Morgan (1968) established the modern theory of plate tectonics & its basic mechanisms (awarded National Medal of Science, Nov 6)

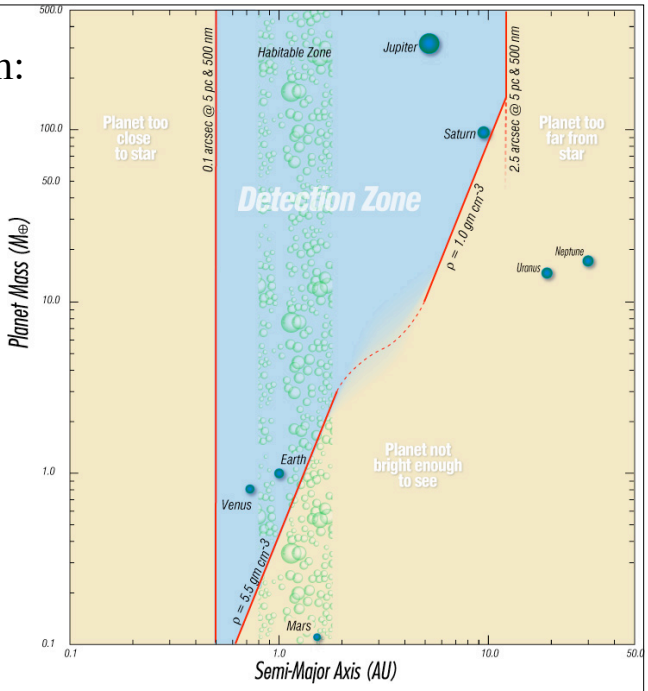


Terrestrial Planet Finder (TPF) Goal:
resolve an ancient/fundamental question.

There are infinite worlds, both like and unlike this world of ours.
-**Epicurus** (341-270 BC)

There cannot be more worlds than one.
-**Aristotle** (384-322 BC)

Detection problem: Capabilities of a 4m-TPF/HST-2 at a distance of 5 pc (16 ly) with Solar System objects shown for comparison.



Characterization Problem: Determine atmospheric and surface properties with special attention to "biomarkers".

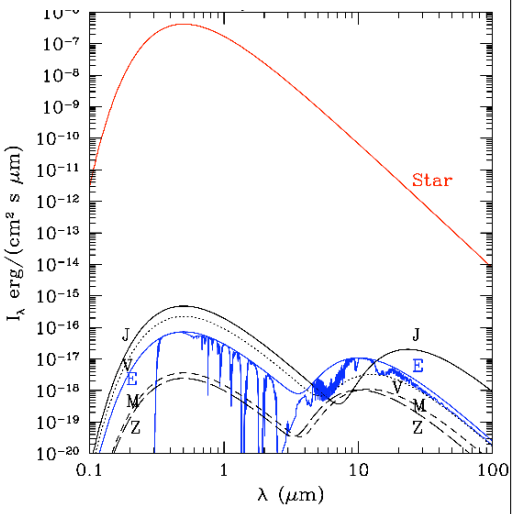
TPF Programatic Goals & Status

- DETECT: Search 150-300 nearby (5-15 pc distant) Sun-like stars for Earth-like planets. [150 --> 50 ?]
- CHARACTERIZE: Determine basic physical properties and measure "biomarkers".
- Key element of NASA's *Origins* science theme
- 2014 launch? Five year mission duration?
- US$1-2 billion budget? (Internat. mission? *Darwin*?)
- Preliminary mission architecture studies completed.
- Technology development projects in progress.
- TPF precursor mission(s) this decade (Kepler).

Solar system at 10 pc

- **Visible**
- **Earth/sun is 10^{-10}**
- **Zodi relatively small (many pixels on target)**

- **Infrared**
- **Earth/sun is 10^{-7}**
- **Zodi relatively large (one pixel on target) ~100 times shown**



With/without life

production rate:

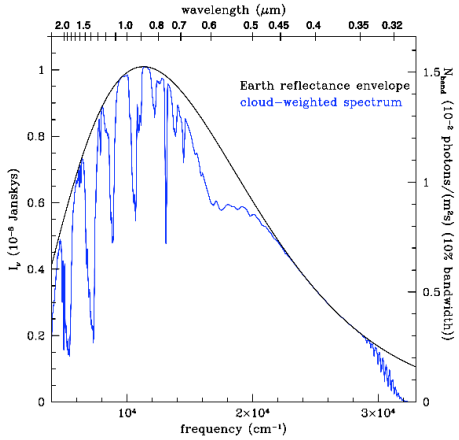
Gas	log(life/no_life)
O_2	5
N_2O	3
CH_4	5
CO_2	-3

atmospheric abundance:

Gas	log(life/no_life)
O_2	2
N_2O	2
CH_4	3
CO_2	-3

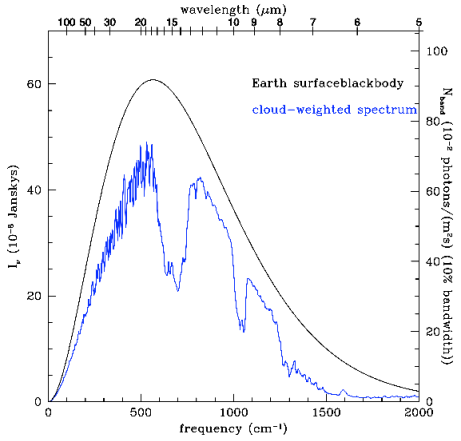
Rough order-of-magnitude values.
Other gases not readily detectable: H_2, NH_3, HCl, CO, N_2

Visible reflection spectrum



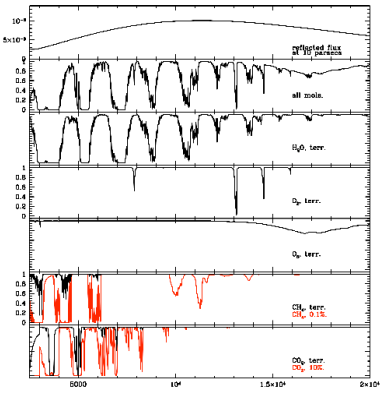
- **Absorption spectra of O_3, O_2, H_2O dominate.**
- **Rayleigh scattering will add to spectrum.**

Infrared emission spectrum



- **Absorption spectra of O_3, CO_2, H_2O dominate.**
- **CH_4 and N_2O are partly hidden by H_2O.**

Molecule-by-molecule spectra



Envelope

all

H_2O

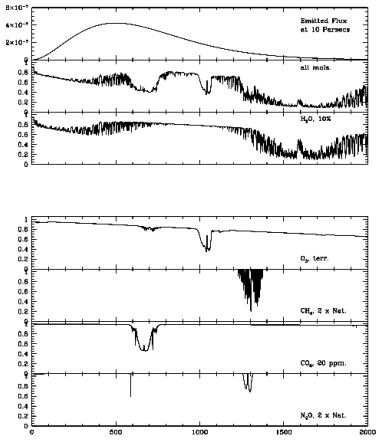
O_2

O_3

CH_4

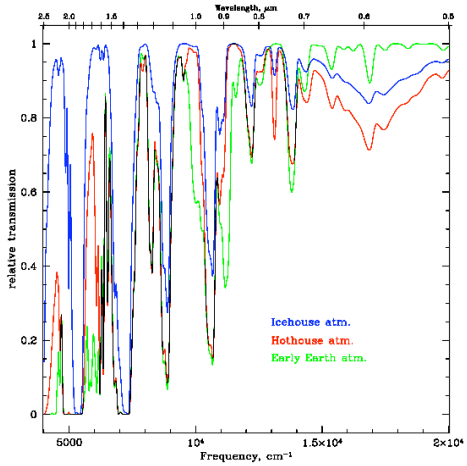
CO_2

N_2O



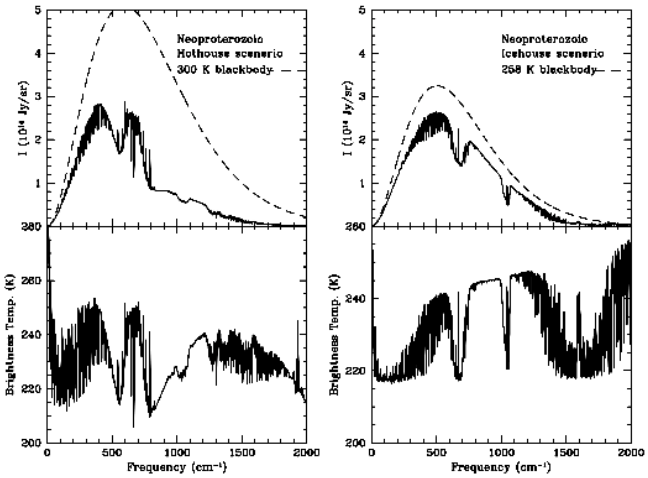
Visible **Infrared**

Earth hothouse, icehouse, methane burst



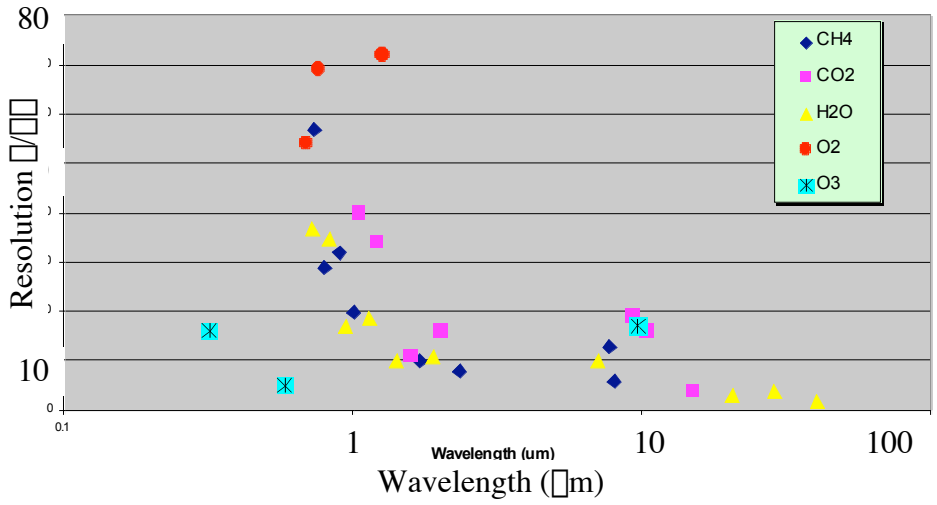
- **Neoproterozoic snowball Earth oscillated between icehouse (blue) to hothouse (red) ~0.7 Ga.**
- **Methane burst condition (green), possibly freeing ocean floor methane clathrate ~0.2 Ga and ~0.06 Ga.**

Earth hothouse, icehouse



- **Neoproterozoic CO_2-dominated (hot) Earth (left) and CO_2-depleted (snowball) Earth (right). Infrared.**

TPF Biomarkers



Species and properties: tradeoffs

	Visible	Infrared
CO_2	Yes (if abundant)	Yes
H_2O	Yes	Yes
O_2	Yes	No
O_3	Yes	Yes
CH_4	Yes (if abundant)	Yes (if abundant)
N_2O	No	Yes (if abundant)
temperature	Yes (derived,surf.)	Yes (direct, strat.)
pressure	Yes	No
radius, mass	Yes (inferred)	Yes
Red Edge	Yes	No

Time to detect biomarkers on Earth at 10 pc

	O_2 oxygen	O_3 ozone	H_2O water	CO_2 carbon dioxide
abundance	21%	6 ppm	0.8%	350 ppm
wavelength	0.76 □m	0.59 □m	1.00 □m	2.00 □m
8-m coronagraph	9 days	3 days	1 day	50 days
wavelength	___	9.6 □m	7 or 28 □m	15.2 □m
infrared interferometer	___	7 days	3 days	2 days

Scattered light model of Earth

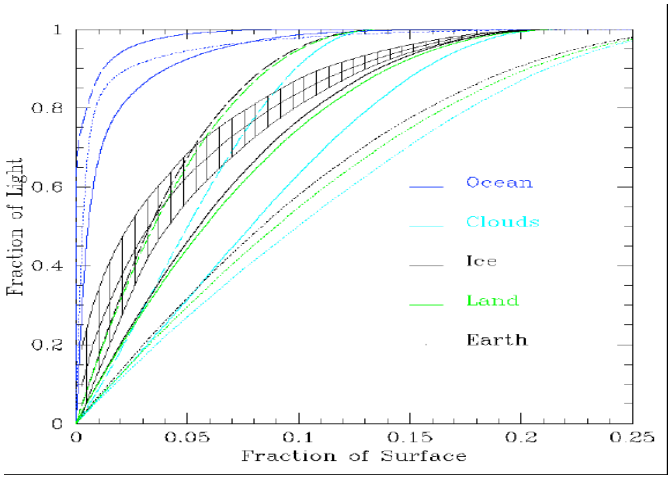
- 180 x 360 (one sq deg) pixel map of Earth
- Pixel classification by satellite imagery (6 types)
- BDRFs - Bidirectional Reflectance Functions
- Single scattering, no elevation variations
- Gray cummulus clouds only
- Four broad wavelength bands: B, G, R, NIR

Details of Map

- Water with waves (specular & isotropic components)
- Permanent ice (strong backscattering)
- Seasonal/sea ice (80% dirty ice, 20% dirt)
- Bare ground (90% sand, 10% clay)
- Grass/brush land (67% dirt, 33% clover)
- Forested land (75% leaves, 25% peat)
- Cloud coverage from ISCCP database

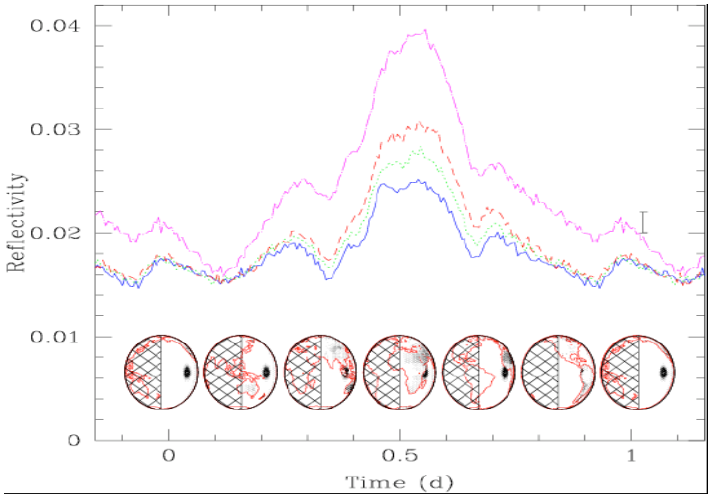
Scattered Light

The scattered light comes from a small part of the planet surface

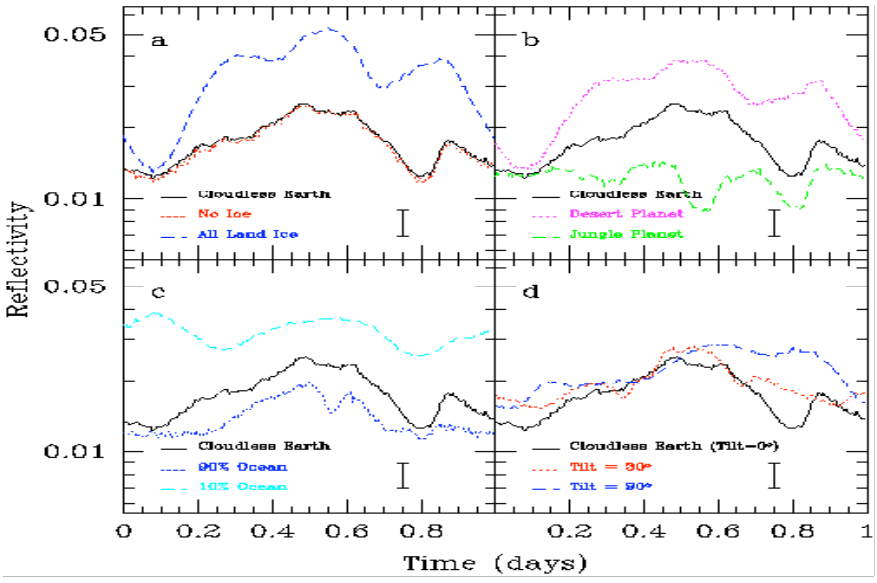


Viewing Geometry

No Clouds: high contrast between land and ocean

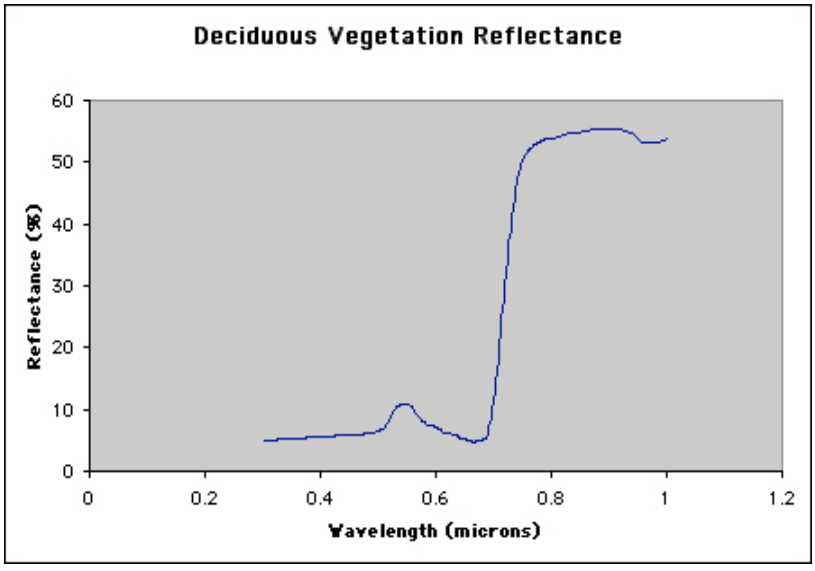


Hypothetical Extrasolar Planets



Plants in visible versus near infrared light

THE RED EDGE



Optical Plant Signature as a Biomarker

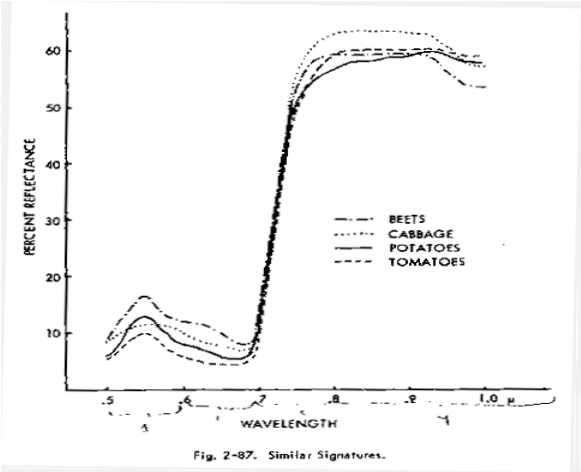
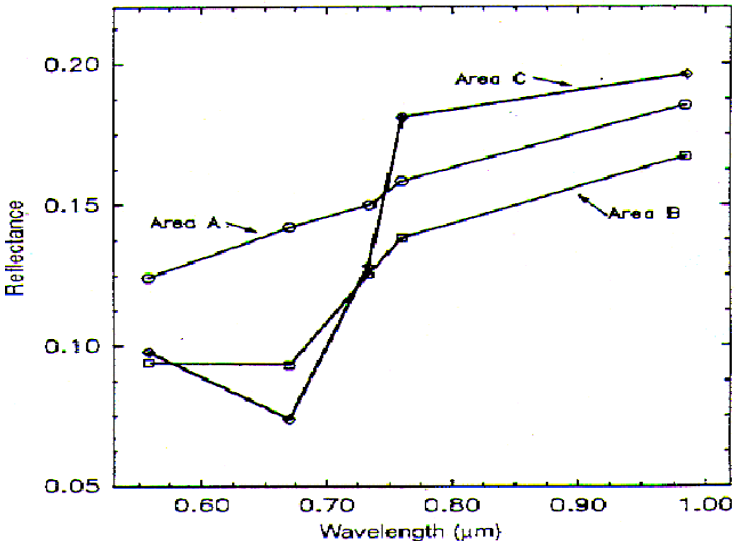


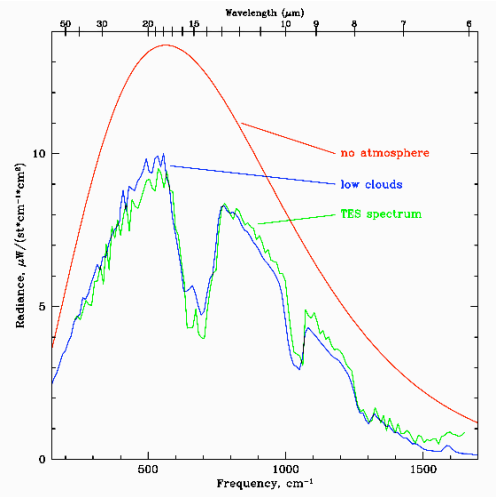
Fig. 2-87. Similar Signatures.

- Chlorophyll causes strong absorption blueward of 0.7 μm.
- The high reflectance red-ward of 0.7 μm is from light scattering in the gaps between plant cells.
- This "red edge" is an evolutionary adaptation which helps plants stay cool enough to allow efficient photosynthesis.

Optical Plant Signature as a Biomarker



Infrared spectrum of Earth: validation

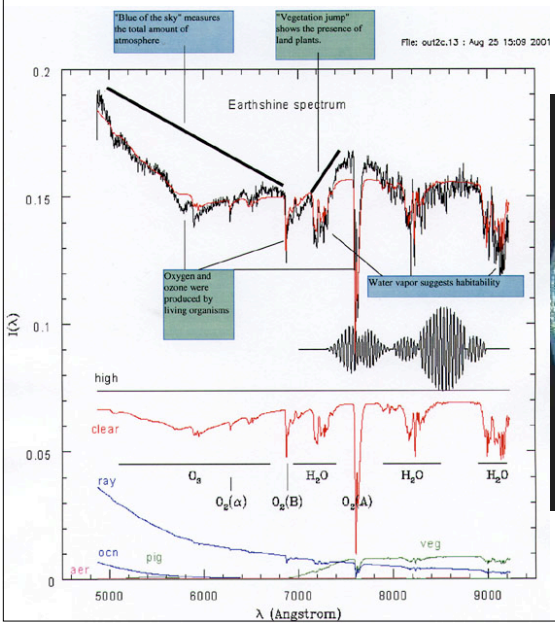


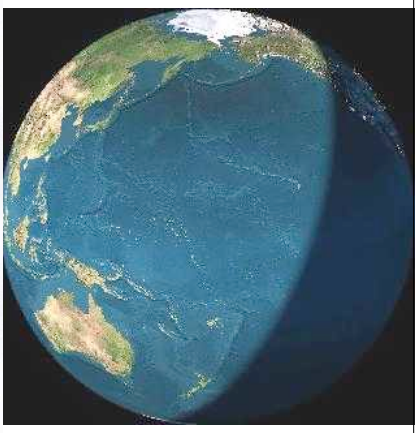
- **Integrated light of Earth, seen by TES enroute to Mars; CO_2, O_3, H_2O dominate.**

Earthshine: Sunlight scattered by the Earth illuminating the dark side of the Moon allows observation of the Earth's total (integrated) light.

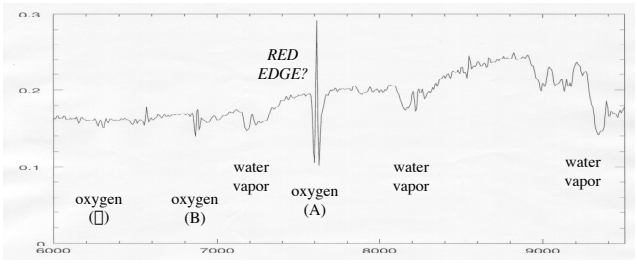


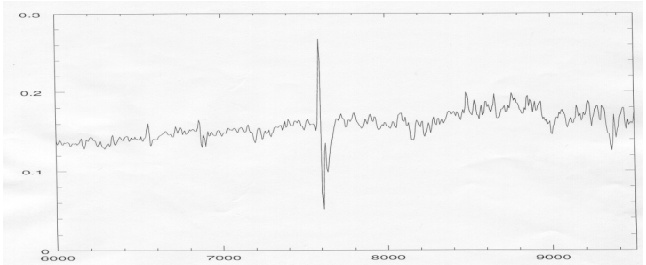

Earthshine Reveals Visible Spectrum

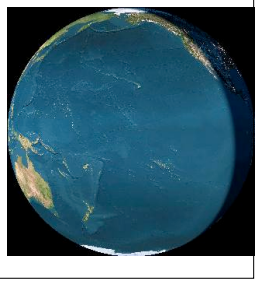


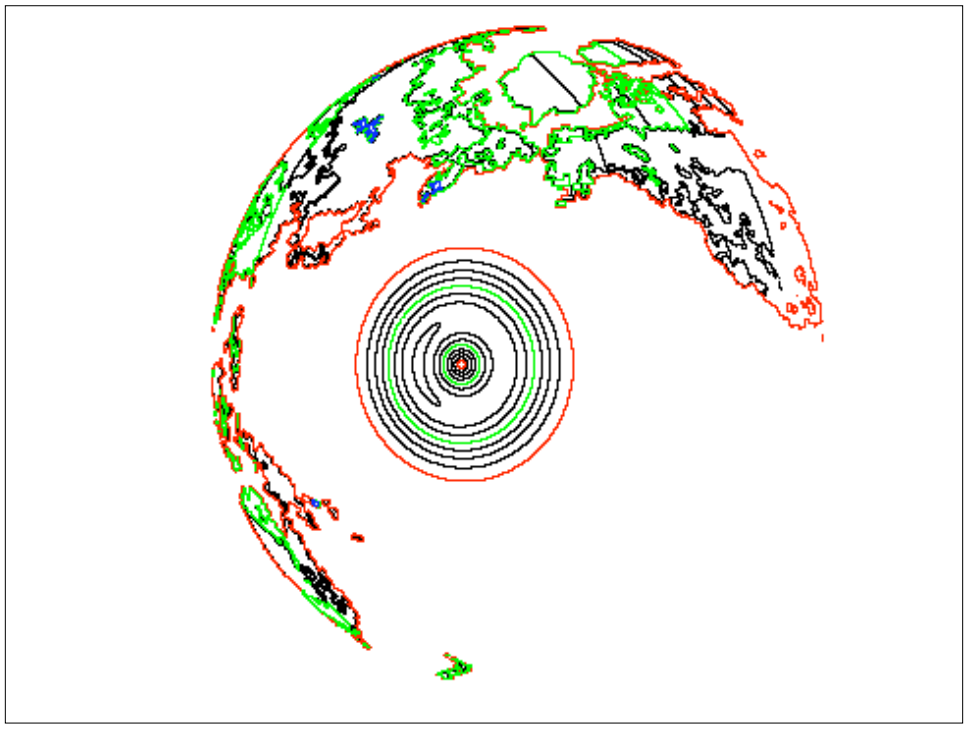


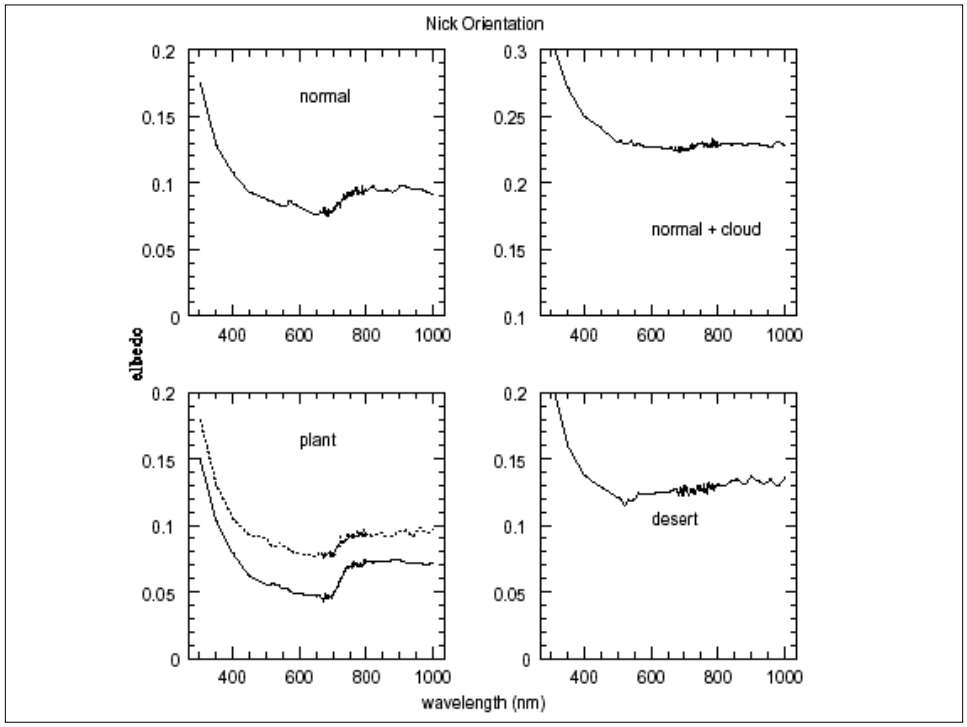
APO 3.5m Earthshine Spectra (Feb 2002)

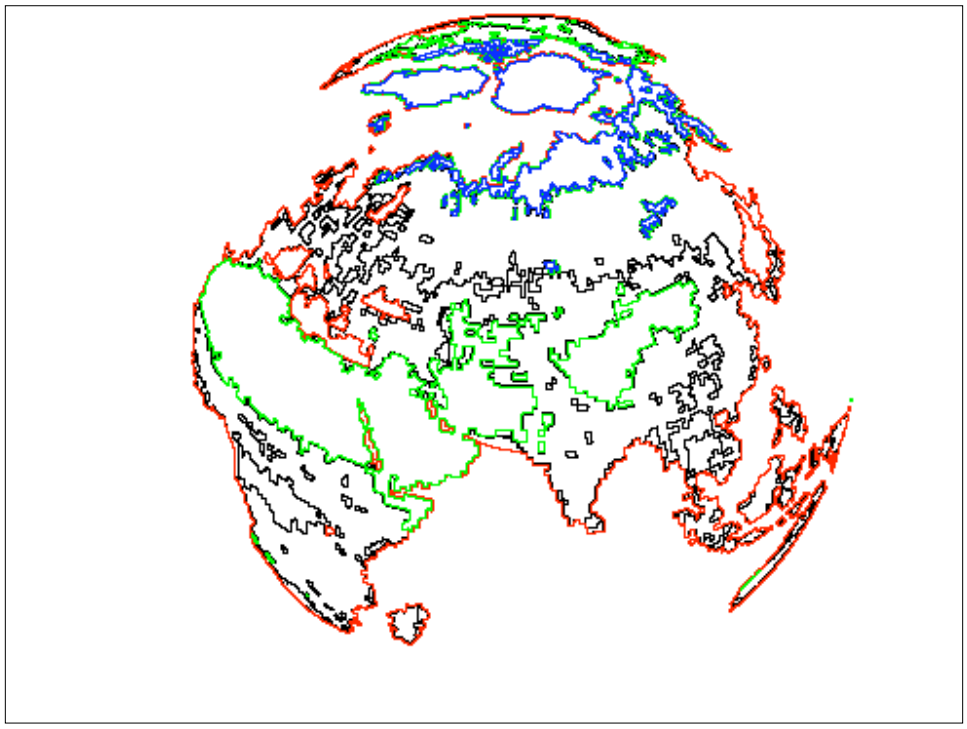


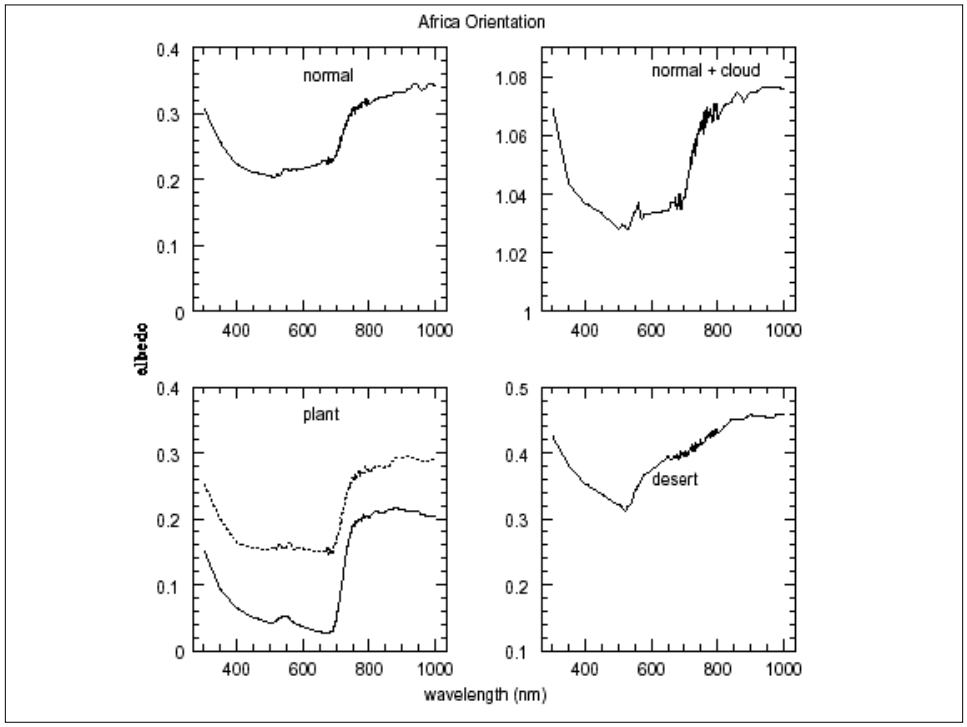






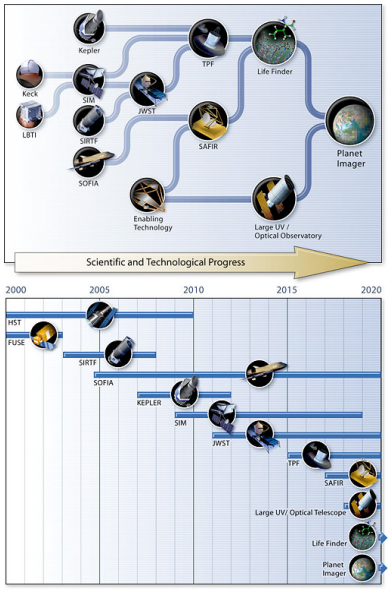

Nick Orientation
normal
normal + cloud
plant
desert
albedo
wavelength (nm)
0.2
0.15
0.1
0.05
0
0.3
0.25
400
600
800
1000



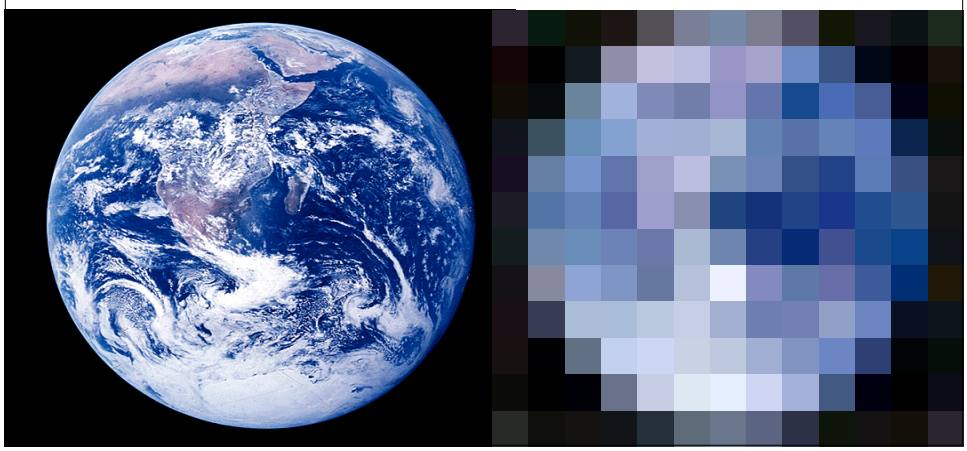

Africa Orientation
normal
normal + cloud
plant
desert
albedo
wavelength (nm)
0.4
0.3
0.2
0.1
0
1.08
1.06
1.04
1.02
1
0.5
0.4
0.3
0.2
0.1
400
600
800
1000

Beyond TPF: Names/Dreams of Future Missions

- Life Finder: Carry out detailed, high signal-to-noise observations of nearby extrasolar planets discovered by TPF.
- Planet Imager: Resolve the images of nearby extrasolar planets into perhaps 100 or so pixels.
- Sometime after 2020?



Simulated *Planet Imager* View of the Earth



Summary

- Detection and characterization of extrasolar terrestrial planets orbiting nearby stars is technically very difficult but is expected to be practical within the foreseeable future.
- Optical or mid/thermal-IR spectroscopy can reveal the presence of oxygen, water vapor, carbon dioxide and other major molecular constituents of such a planet's atmosphere.
- Diurnal light curves of extrasolar planets will be powerful characterization tools for surface properties: weather, climate, etc.
- Earthshine & spacecraft allow us to observe the Earth as if it were an extrasolar planet and thus check our theoretical expectations.
- The first direct detection extraterrestrial life might be due to the color of (dumb!) plants rather than signals from advanced technical civilizations!

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