

Honors Seminar 292 — cheat sheet for 10/30/2019 — Andrew Baker

Sagan et al. (1993)

You should read the whole article. Key questions:

1. What do the authors mean by the phrase “ground-truth Earth”, and what is its significance?
2. How does the authors’ dictum “Life is the hypothesis of last resort” relate to the principle of Occam’s razor?
3. What evidence do the authors amass to argue that the Earth is rich in water, and specifically *liquid* water?
4. How does the authors’ dictum “we could not be confident that present circumstances are typical of Earth’s history” relate to the Copernican principle?
5. What do the presence of atmospheric O₂, O₃, CH₄, and N₂O (oxygen, ozone, methane, and nitrous oxide) tell us about the “possible” existence of life on Earth?
6. Can you suggest a more direct phrasing of “flatulence from domesticated ruminants” (one of the sources of atmospheric methane on Earth)?
7. Figure 3, as also discussed in the text, shows “an unusual spectrum” with a sharp break for the region identified as “Area C”. What is responsible for this sharp break?
8. Could regular geometric patterns in satellite imaging invariably be used to argue for the presence of life?
9. What are the properties of the radio emission that *Galileo* detected that suggest it is produced (a) on the surface of the Earth, and (b) by a technologically advanced civilization?
10. If *Galileo* had failed to detect any evidence of life on Earth, what would the implications have been for the possible existence of life on other worlds in the solar system?

Key terms:

- **albedo** = fraction of incident light that a particular material reflects
- **amagat** = a unit of number density (number of species X per unit volume)
- **amplitude modulation** = the transmission of information on a “carrier wave” of fixed frequency by varying the amplitude (i.e., intensity) of emission; this is the technique that is used by AM radio broadcasters (“FM” stands for the alternate strategy of “frequency modulation”)
- **aurora** = “northern lights” or “southern lights” produced in Earth’s polar regions when charged particles accelerated by the Earth’s magnetic field collide with neutral particles in the atmosphere

- **band** = in the context of a spectrum, a term referring to a broad feature that results from many overlapping narrow features due to a single species
- **dielectric** = adjective or noun referring to a substance that does *not* conduct electricity
- **dielectric constant** = a number that quantifies the degree to which a substance does not conduct electricity
- **exobase** = lower boundary of the exosphere, which is the highest layer in the Earth's atmosphere and the one from which atoms can escape to space
- **gas-phase** = adjective describing material of a particular chemical composition that is gaseous rather than liquid or solid
- **Hartley bands** = a set of absorption features in the spectrum of the Earth's atmosphere that are due to ozone (O₃); their wavelengths lie between 200 nm and 300 nm
- **heat capacity** = a number that quantifies the amount of heat energy required to raise the temperature of a substance by a fixed amount (per unit mass)
- **interferometric** = adjective referring to an array of telescopes that work together to deliver an image of very high resolution
- **ionosphere** = the upper layer of the Earth's atmosphere (technically, coinciding with the thermosphere) in which atoms can be ionized by the Sun's radiation; the ionization fraction increases on the side of the Earth facing the Sun, and decreases on the side away from the Sun
- kcal mol⁻¹ = units describing the strength of a chemical bond (essentially, the energy required to break all of the bonds in a sample, normalized to the number of molecules in the sample)
- **mesopause** = boundary between the third-lowest (mesosphere) and fourth-lowest (thermosphere) layers of the Earth's atmosphere, which is notable for having the lowest temperature in the atmosphere, thanks to low solar heating and high CO₂ cooling
- **narrow-band filter** = a filter that lets through light over only a very limited range in wavelength
- **nitrogen fixing** = process by which nitrogen is converted from its atmospheric form (N₂) to compounds like ammonia or nitrogen dioxide; on the Earth, this process is undertaken by a number of bacterial species, although it can also proceed in the absence of life
- **non-thermal** = adjective describing electromagnetic radiation that does *not* have the spectrum expected for material that is radiating merely because it is hot
- **optical depth** = a dimensionless number that describes the amount of material along a sightline; specifically; if the optical depth of absorbing material is τ , then the amount of background light will be reduced by a factor $e^{-\tau}$ by the time it reaches us

- **orogenic** = adjective describing a geological process that builds mountains
- **plasma frequency** = for a medium that is partially or fully ionized, the frequency below which electromagnetic radiation simply will not propagate; this is proportional to the square root of the electron density
- **radiometric temperature** = the temperature that a radiating body *would* have if its emission observed at a particular wavelength were entirely due to the fact that it was glowing
- **specular** = mirror-like
- **spin-forbidden** = adjective describing a transition between two electronic energy states that is nominally forbidden by one of the rules of quantum mechanics (specifically, that the sum of electron spins cannot change), and which is therefore relatively unlikely to occur
- **tropopause** = boundary between the lowest (troposphere) and second-lowest (stratosphere) layers of the Earth’s atmosphere; most of the water in the atmosphere, and all of the phenomena we associate with “weather”, lie below this boundary

Arnold et al. (2008)

You should read the whole article. Note that equations (1), (2), and (3) are fairly simple; you should be able to work out what the different terms mean. Key questions:

1. What is “Earthshine”, and how is this different from a directly obtained Earth-averaged spectrum?
2. Why does the author suggest that we look for “missing photons” as a possible biomarker? Would we expect the same photons to be “missing” on a planet orbiting a star whose spectrum is quite different from that of the Sun?
3. How exactly do we extract the Earth’s spectrum from a measurement of Earthshine?
4. How exactly is the Vegetation Red Edge (VRE) defined?
5. How do clouds, oceans, and deserts affect our ability to detect the VRE? How do these factors relate to apparent differences in VRE measurements taken from different sites on the Earth’s surface?
6. How might the measurement of the VRE for an exoplanet be both more and less difficult than its measurement from Earthshine?
7. Do we need a full spectrum to detect VRE, or can we get away with just a couple of measurements of the intensity of emission on opposite sides of the spectral break?
8. How do the properties of life itself affect the detectability and the wavelength dependence of the VRE?

Key terms:

- **airmass** = a number describing how much atmosphere we have to look through when we are aiming a telescope at a particular elevation; at the zenith (straight up), the airmass is 1, and it increases as we point closer to the horizon
- **Chappuis band** = an ozone absorption feature at a wavelength of 602 nm in the visible part of the electromagnetic spectrum
- **continuum** = the smoothly varying component of a spectrum (this is distinguished from the sharp absorption or emission “lines” that are overlaid)
- **ESO NTT** = New Technology Telescope of the European Southern Observatory (this is located in Chile)
- **GOME** = Global Ozone Monitoring Experiment, an instrument mounted on an orbiting satellite that looks down at the Earth at ultraviolet and visible wavelengths
- **Lambertian diffuser** = an idealized spherical object in which the intensity of reflected, scattered, and/or diffused light is the same regardless of how close to the edge of the object we are looking (by way of example, the Sun is nearly Lambertian, but the Moon is not)
- **near-IR** = near-infrared = term referring to radiation at wavelengths slightly longer than those to which our eyes are sensitive ($\lambda \sim 1 - 2.5 \mu\text{m}$)
- **normalize** = apply a correction to some measurement for the size of a sample so that the measurement can be more easily compared to others (e.g., the statement that 73 Rutgers students are in favor of establishing a Department of Astrobiology is less meaningful than the statement that 73 of 513 Rutgers students surveyed, i.e., 14%, are in favor)
- **OHP** = Observatoire de Haute-Provence, an observatory located in southeastern France
- **phase** = degree to which the part of an astronomical body’s surface that is visible to us is illuminated by the Sun or the star it orbits around (the phase of the Moon as seen from Earth is one example)
- **photometric** = adjective referring to the measurement of light from an astronomical body at some wavelength at very high precision
- **POLDER** = a type of experiment to study the Earth’s reflectance (the acronym stands for **P**olarization and **D**irectionality of the **E**arth’s **R**eflectance)
- **Rayleigh scattering** = scattering of light by particles smaller than the wavelength of the light (the reason the Earth’s sky appears blue is that Rayleigh scattering is much more efficient at short wavelengths)

- **resolution element** = an independent pixel in an image or spectrum (if the light from an object or structure falls in only one resolution element, we say it is spatially or spectrally unresolved)
- **S/N** = signal-to-noise ratio (the higher this ratio, the better the quality of the data)
- **spatially resolved** = adjective describing an object or structure in an image for which information can be extracted for at least two independent pixels
- **spatially unresolved** = adjective describing an object or structure in an image for which all of the light is concentrated into a single pixel, and we can recover no information about size or shape
- **TPF** = Terrestrial Planet Finder, a possible future NASA mission
- **transmittance** = the fraction of incident radiation that makes it through some medium