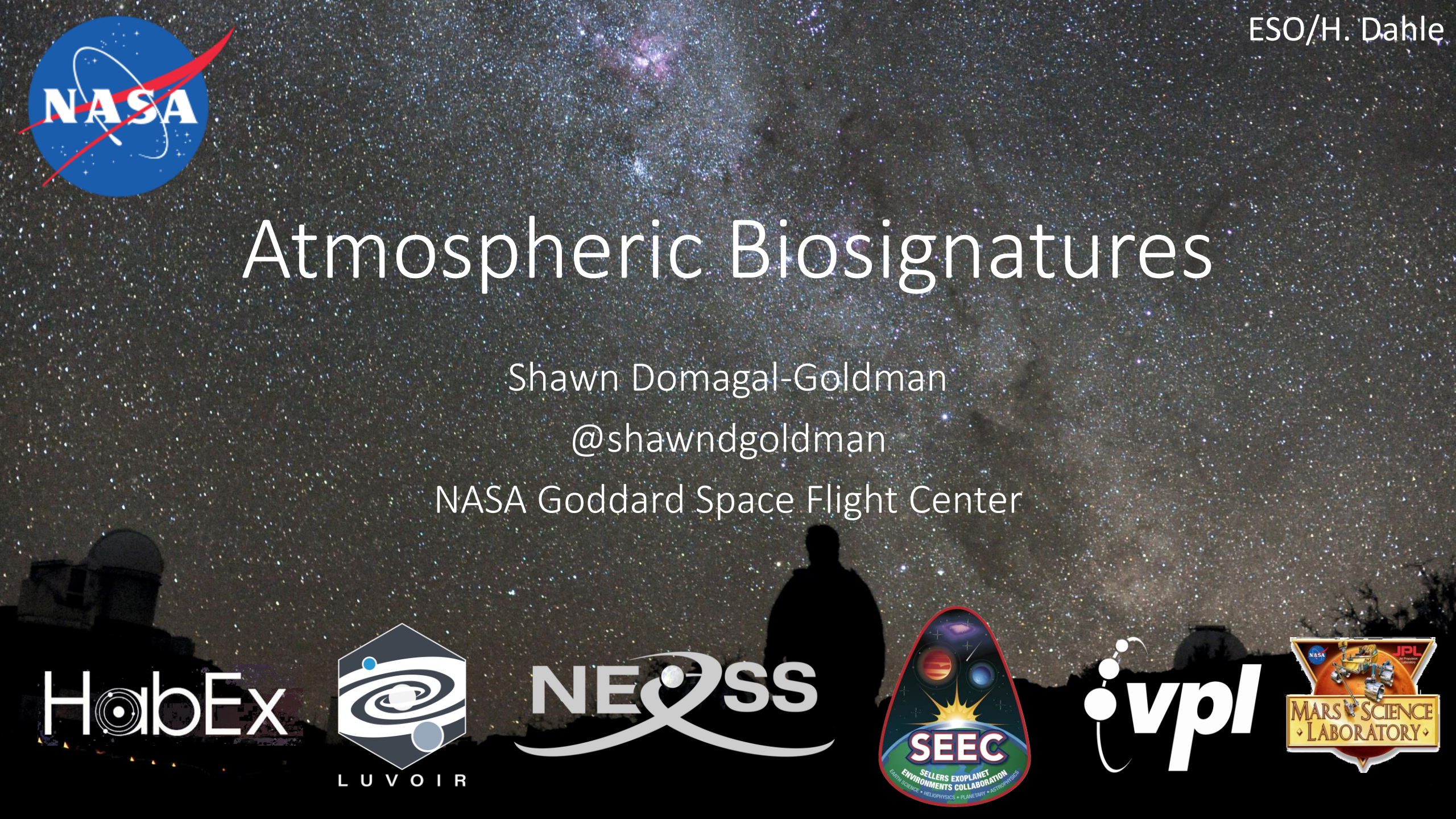


Atmospheric Biosignatures

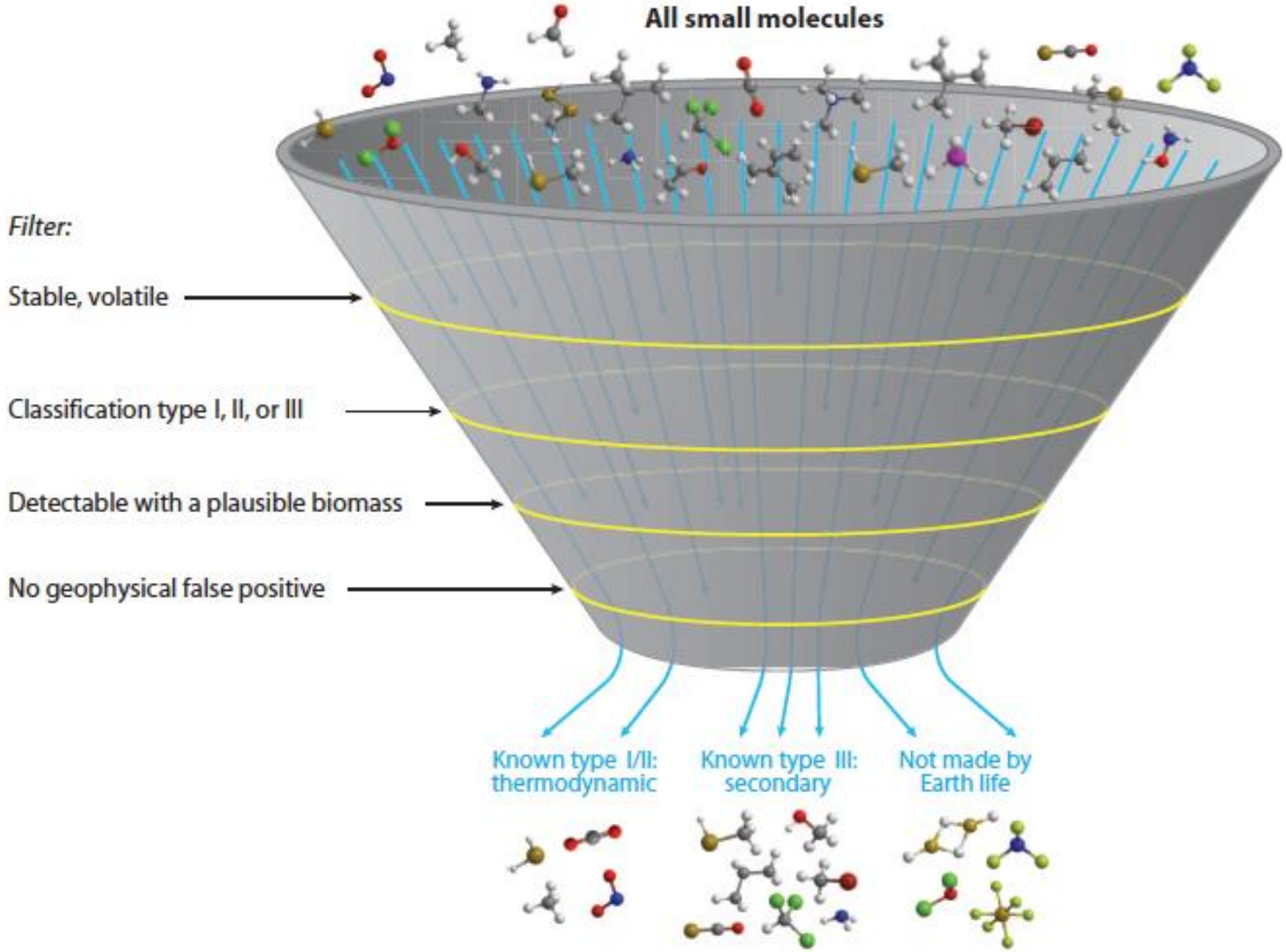
Shawn Domagal-Goldman
@shawndgoldman
NASA Goddard Space Flight Center

A planetary biosignature is a way that life has modified its environment in a potentially detectable way.

NASA/SeaWIFS

Biosignatures need to be:

1. Reliable
2. Survivable
3. Detectable



Meadows 2017
Meadows+ 2017

Seager+ 2014

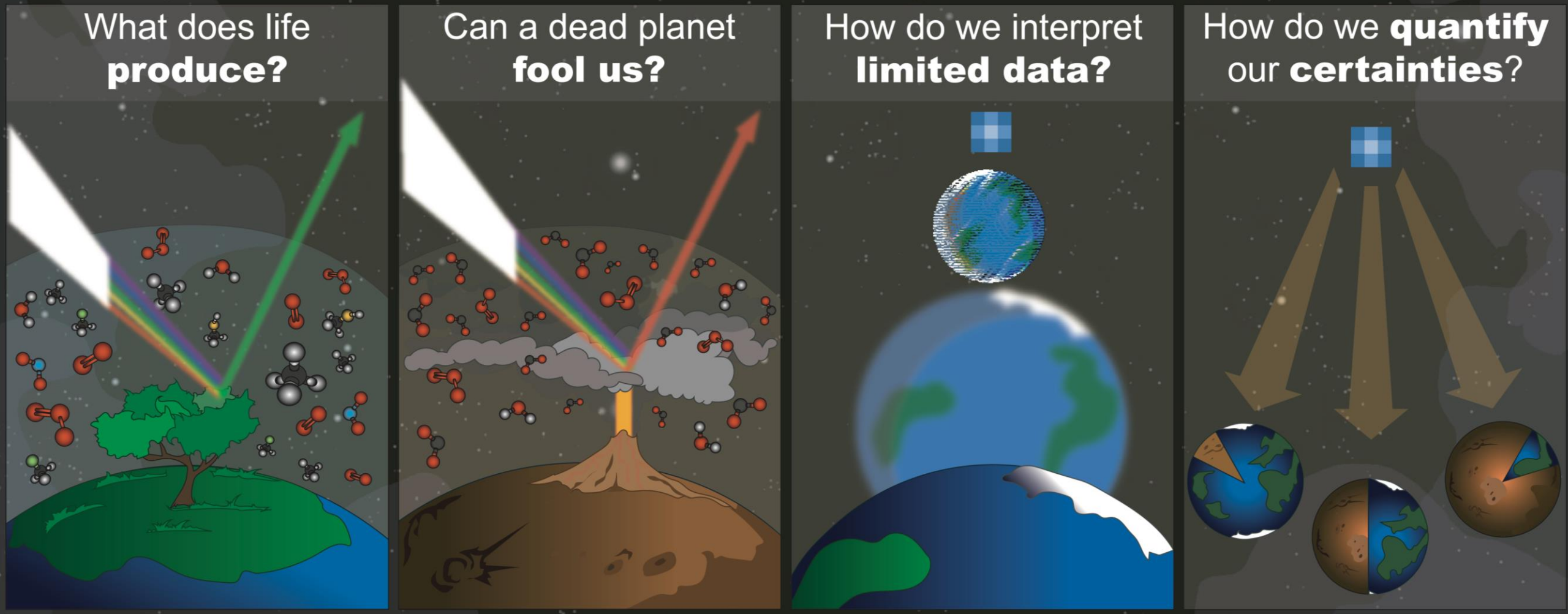


Figure by Aaron Gronstal
NExSS Biosignatures Workshop/SAG16

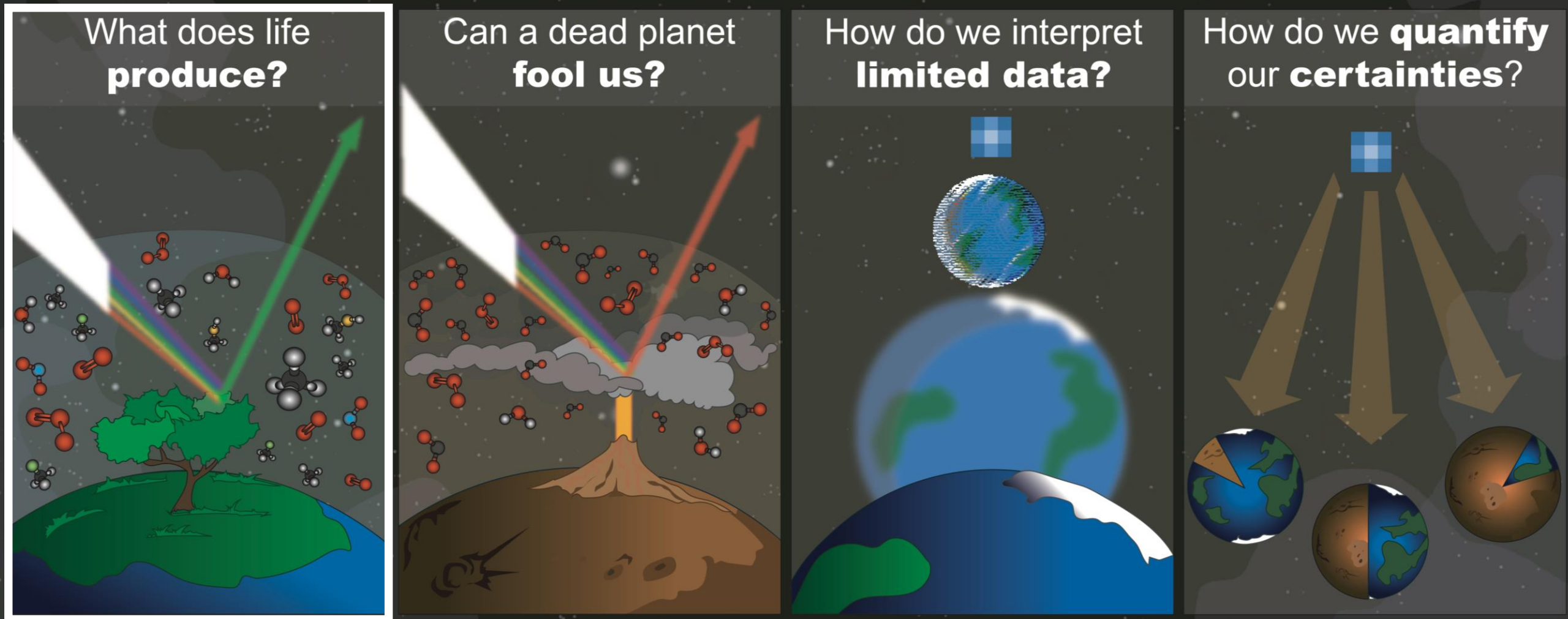
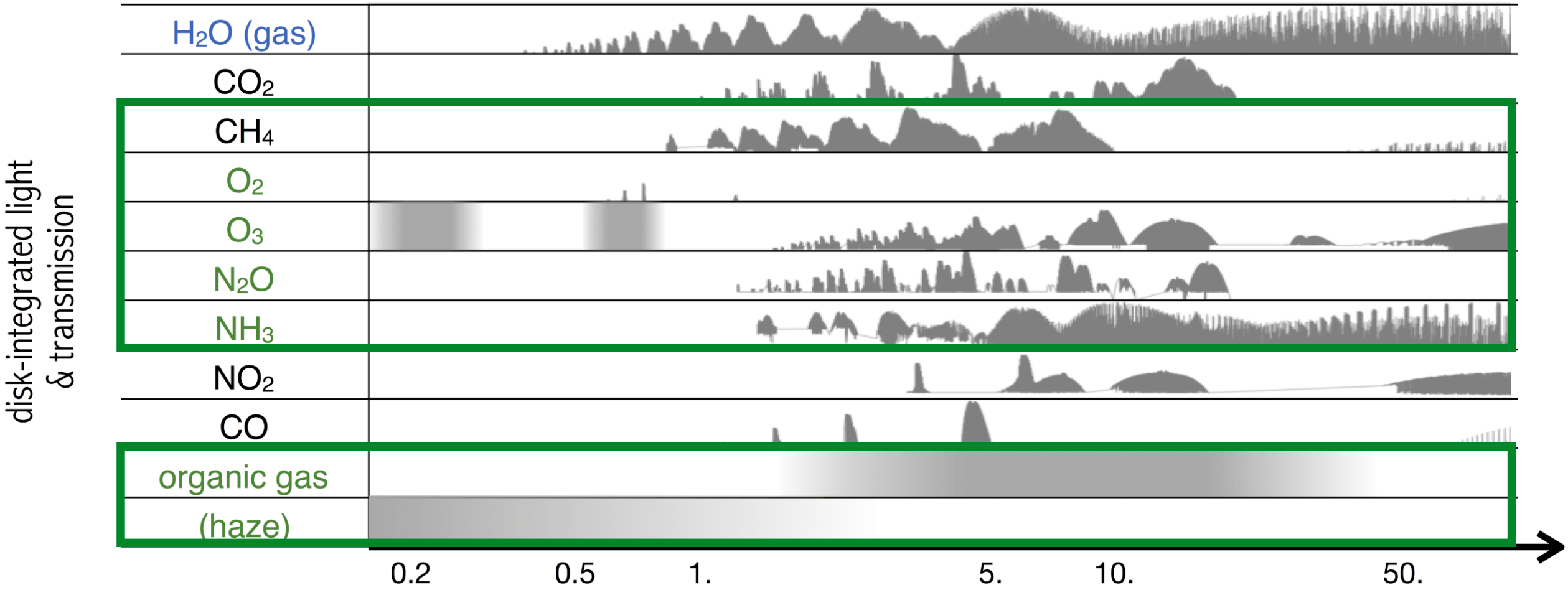


Figure by Aaron Gronstal
NExSS Biosignatures Workshop/SAG16

Features of Potentially Habitable Planets



Fujii+ submitted

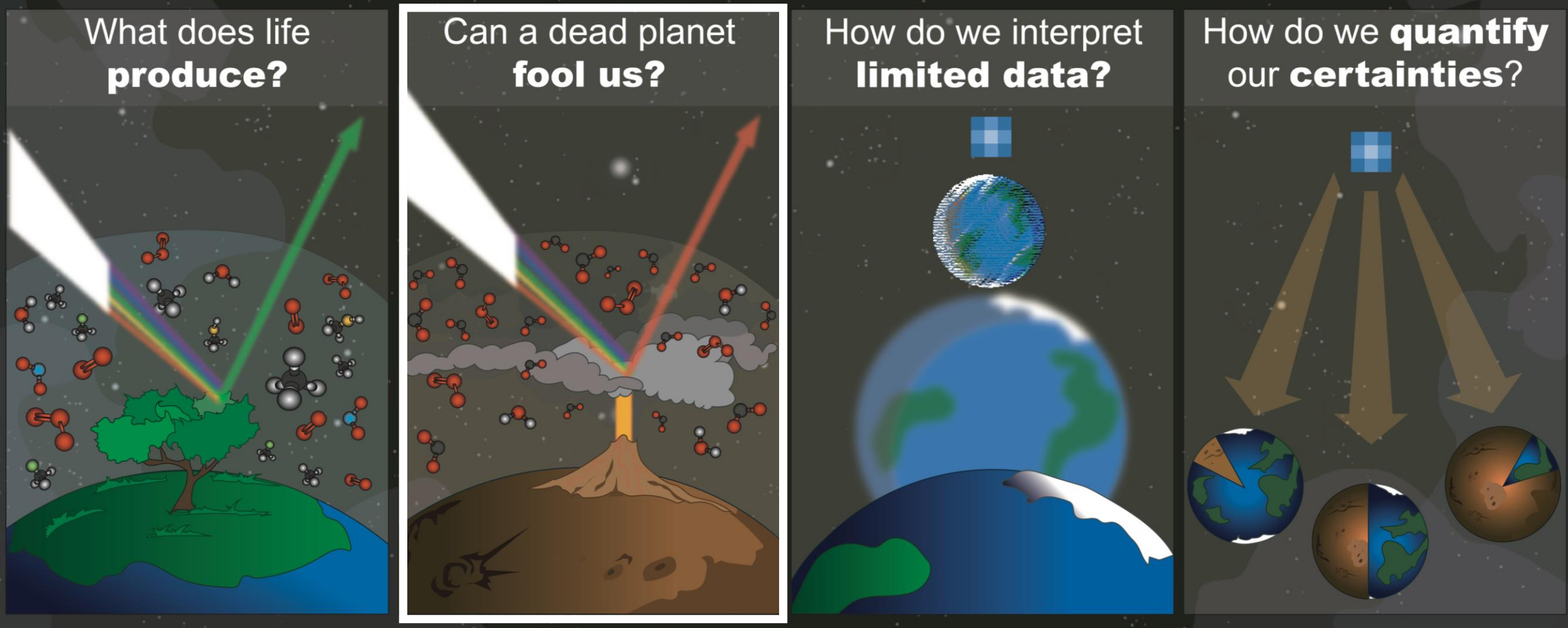
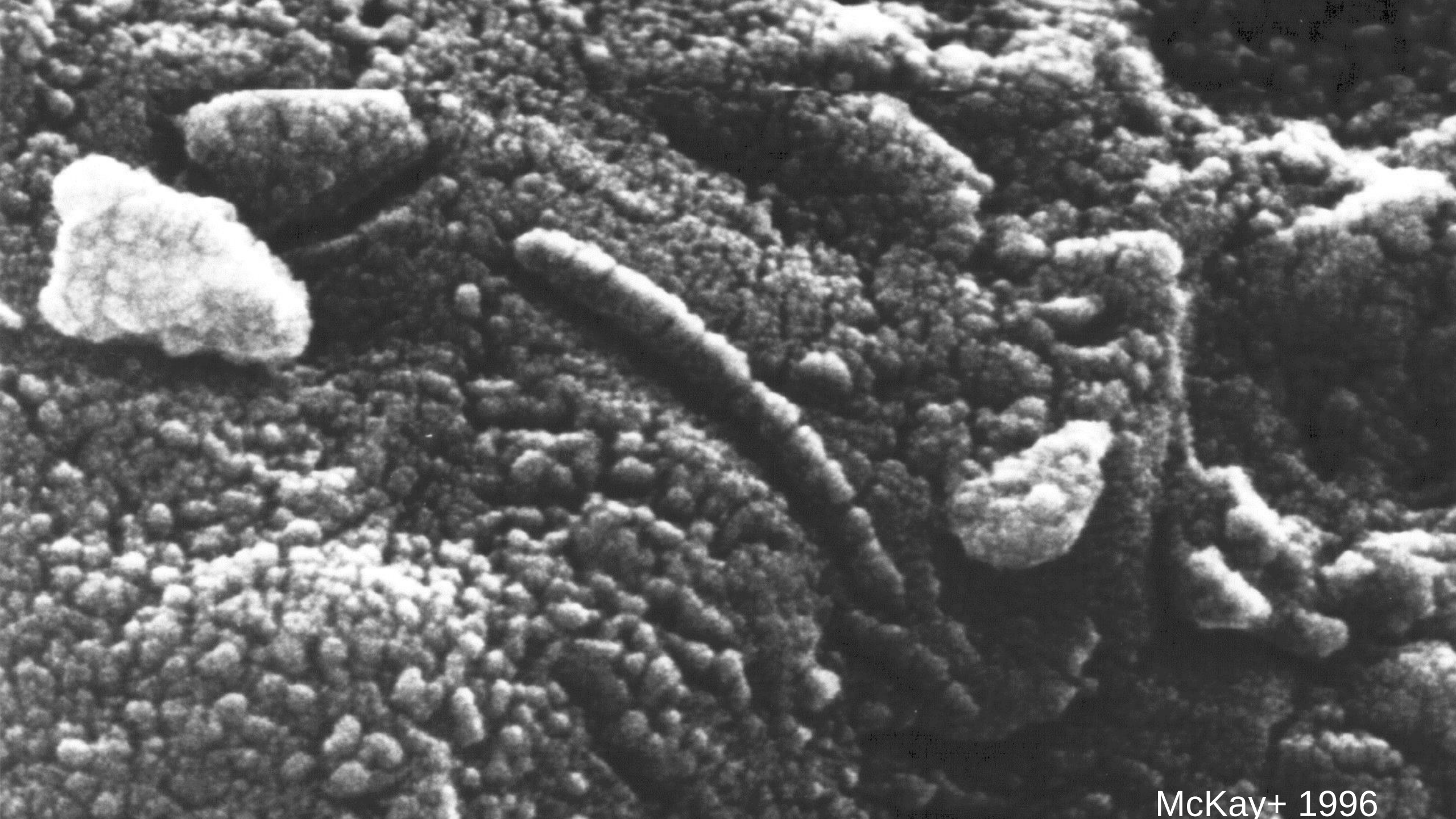
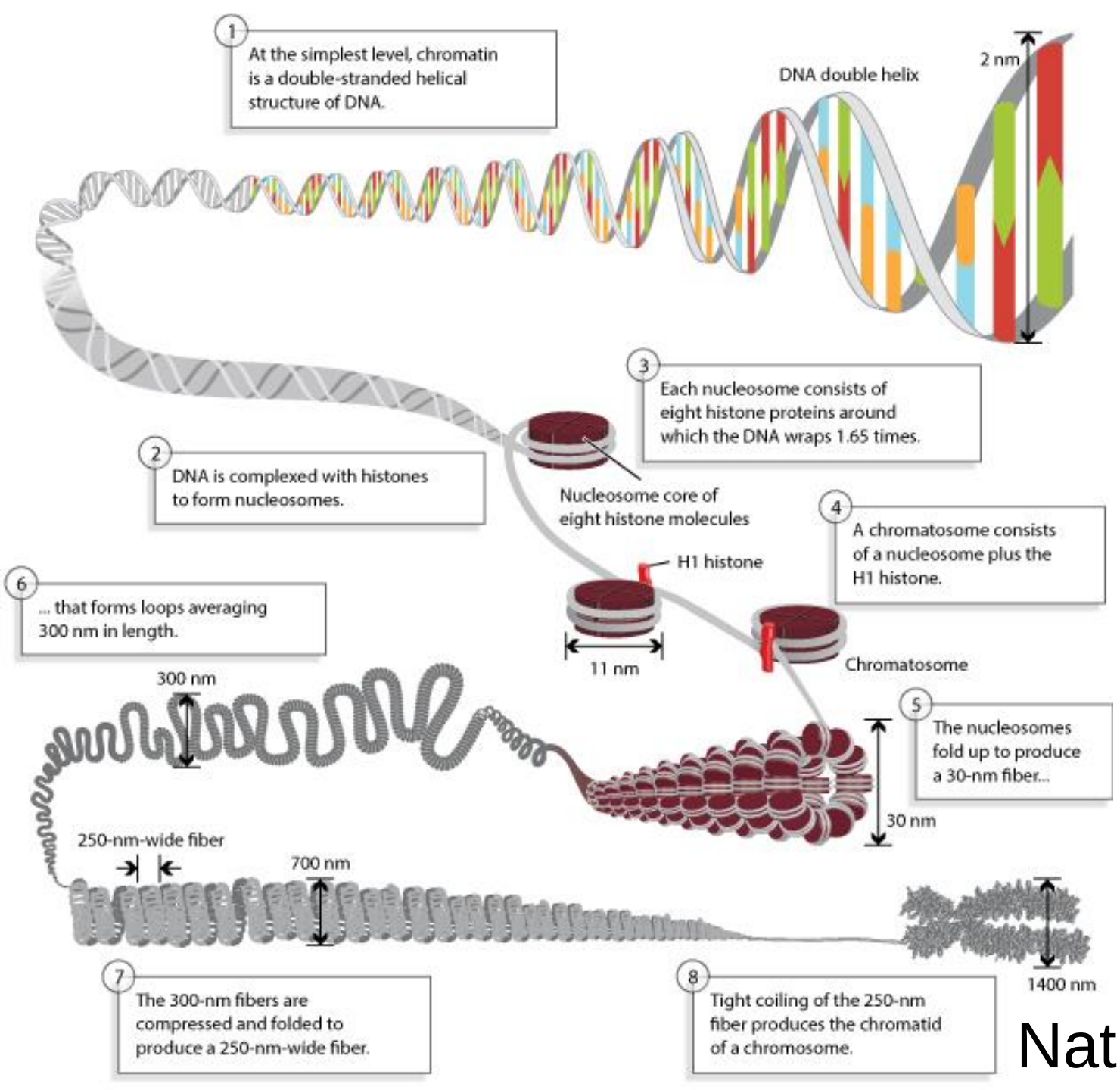
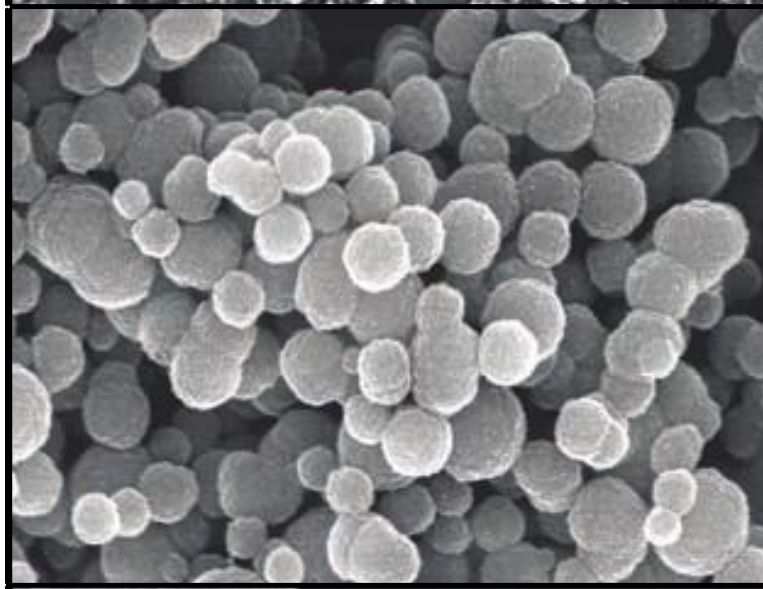


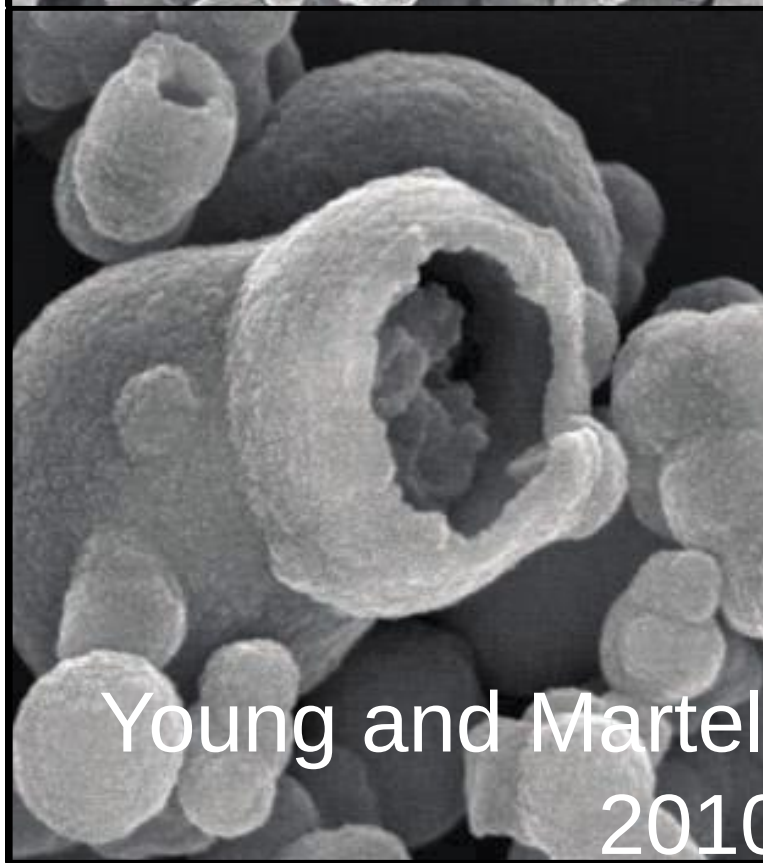
Figure by Aaron Gronstal
NExSS Biosignatures Workshop/SAG16


McKay+ 1996

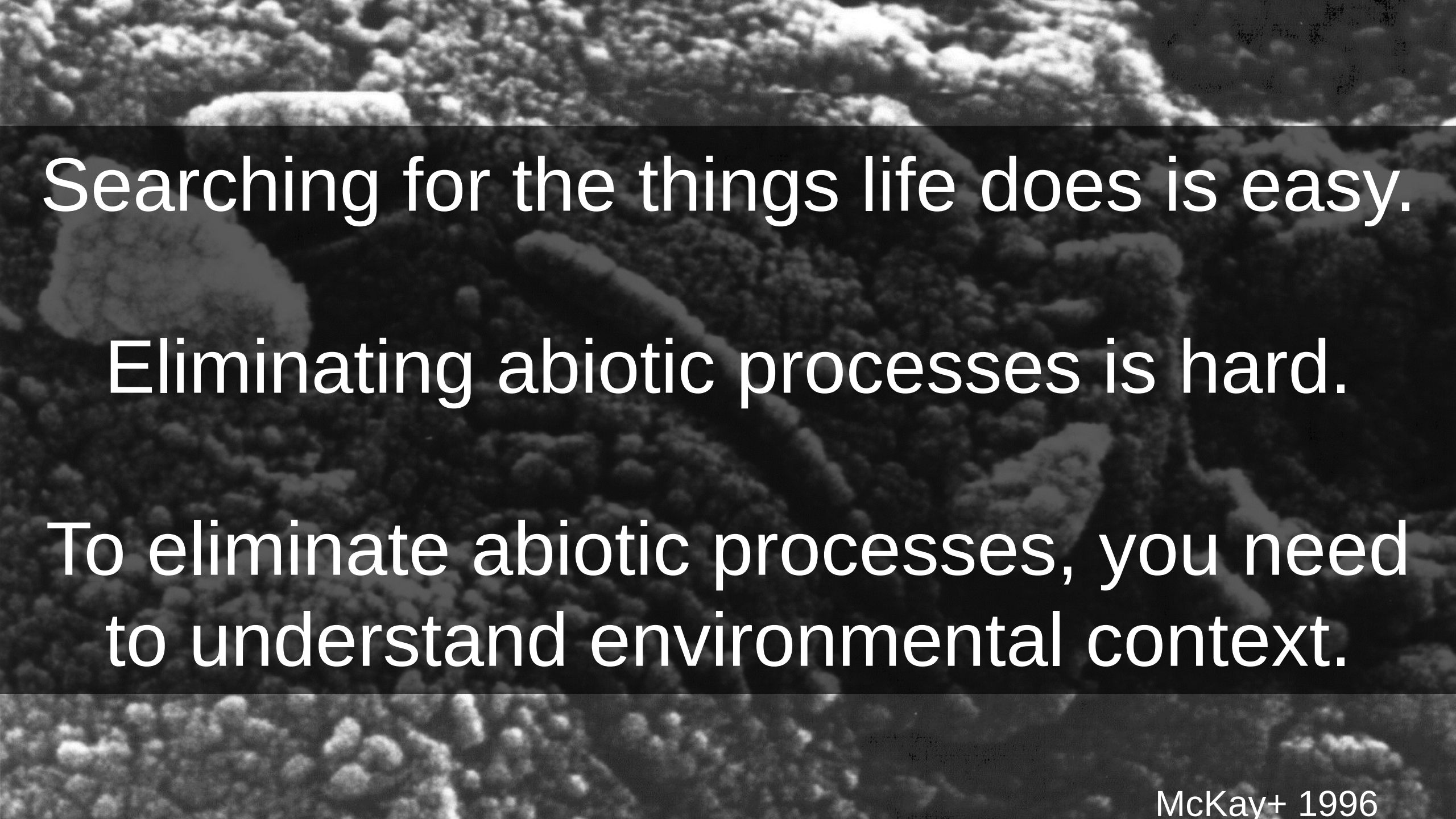


Nature





Young and Martel
2010

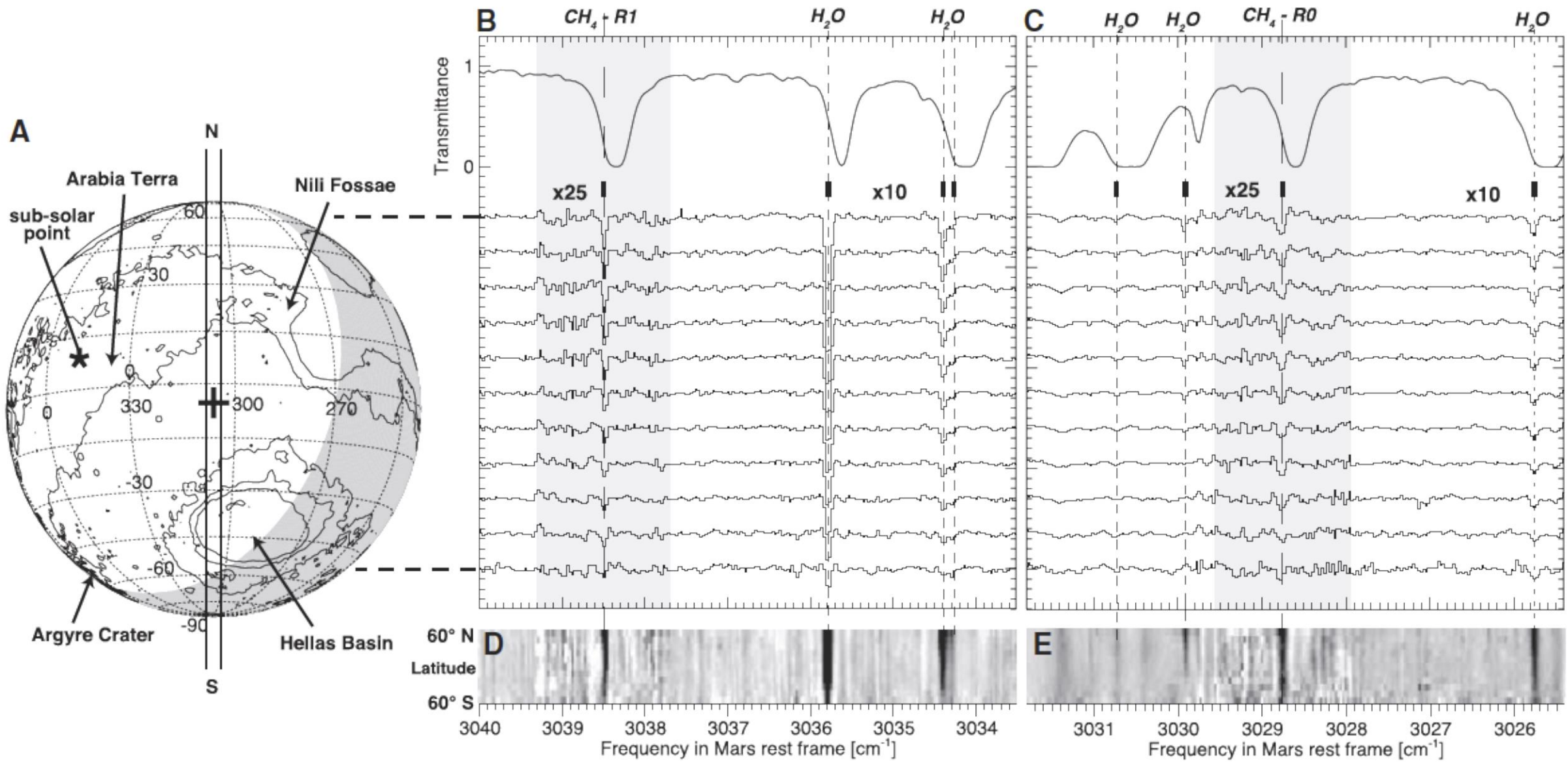


Searching for the things life does is easy.

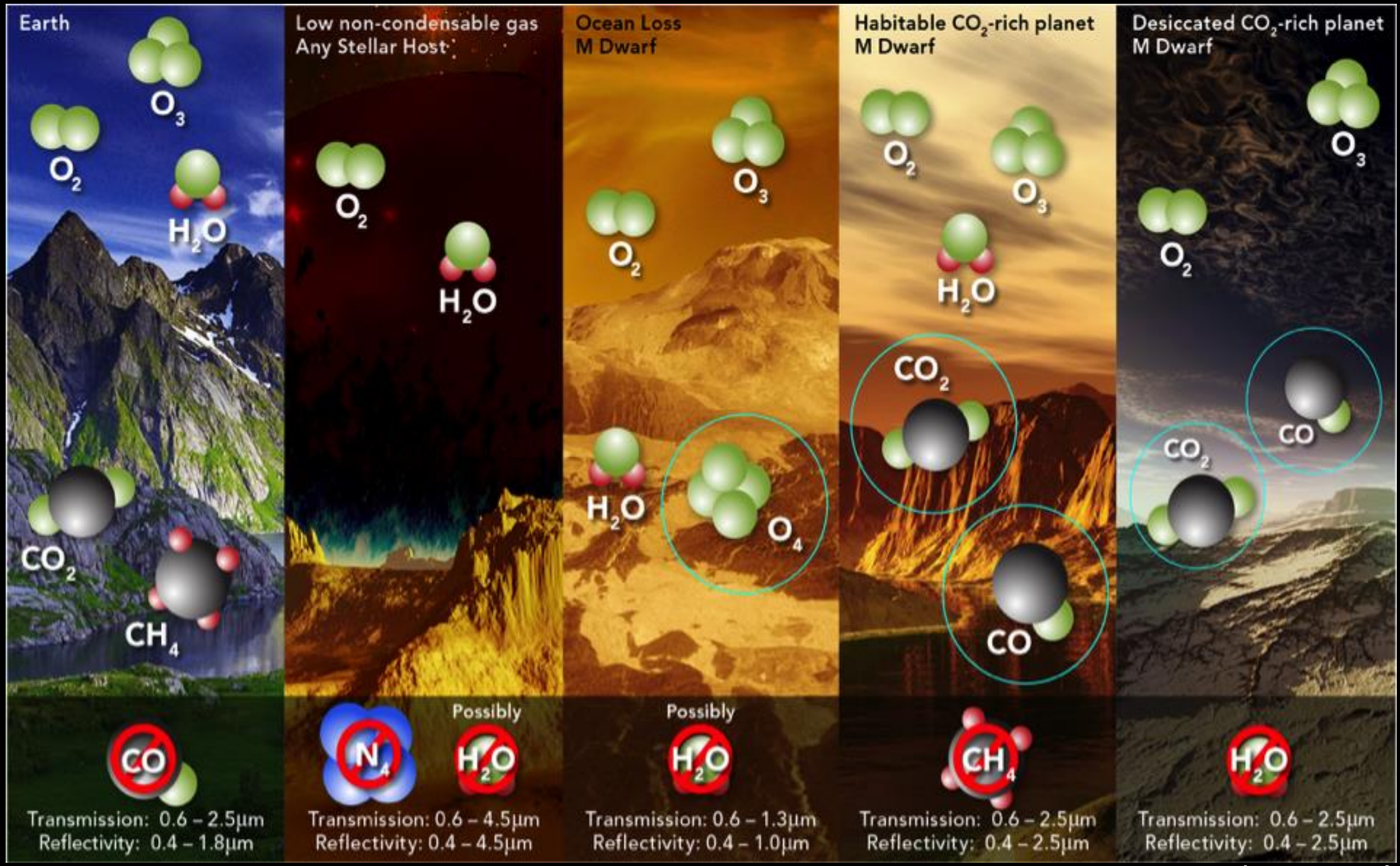
Eliminating abiotic processes is hard.

To eliminate abiotic processes, you need to understand environmental context.

McKay+ 1996

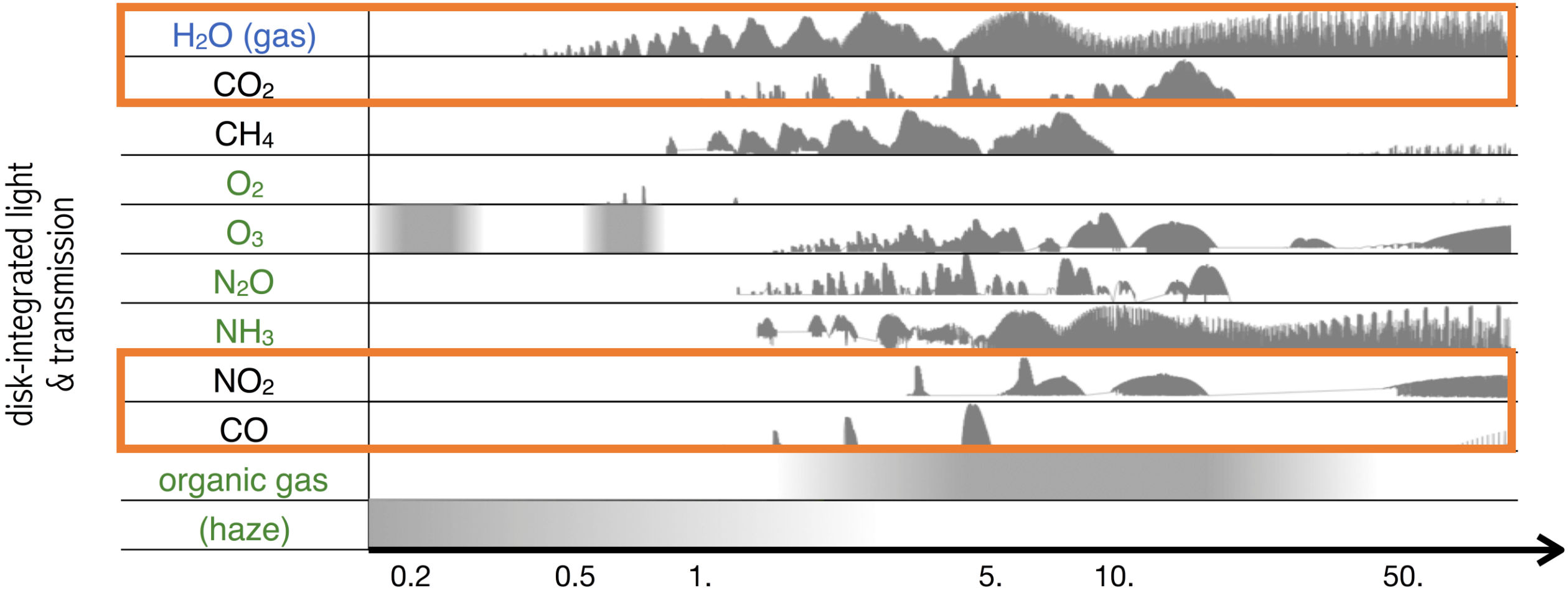


Mumma et al., 2013



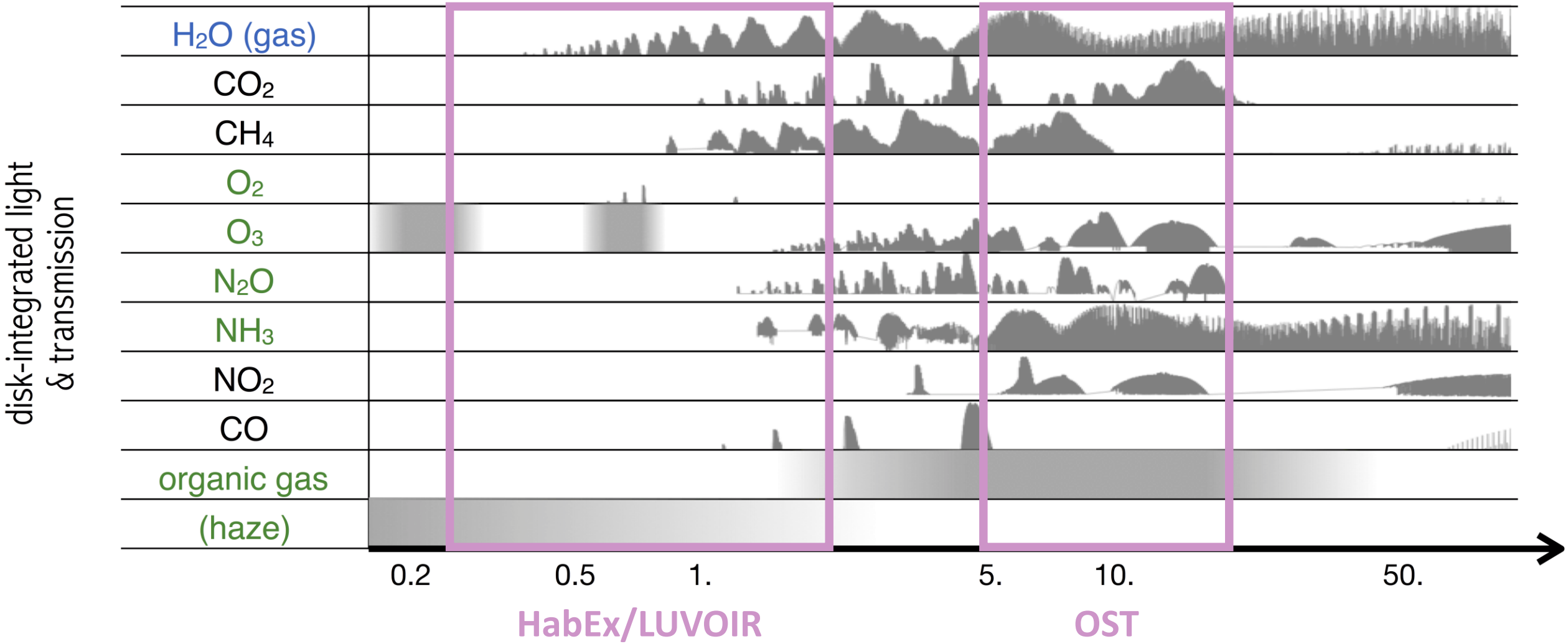
Meadows, et al., 2017

Features of Potentially Habitable Planets



Fujii+ submitted

Features of Potentially Habitable Planets



Fujii+ submitted

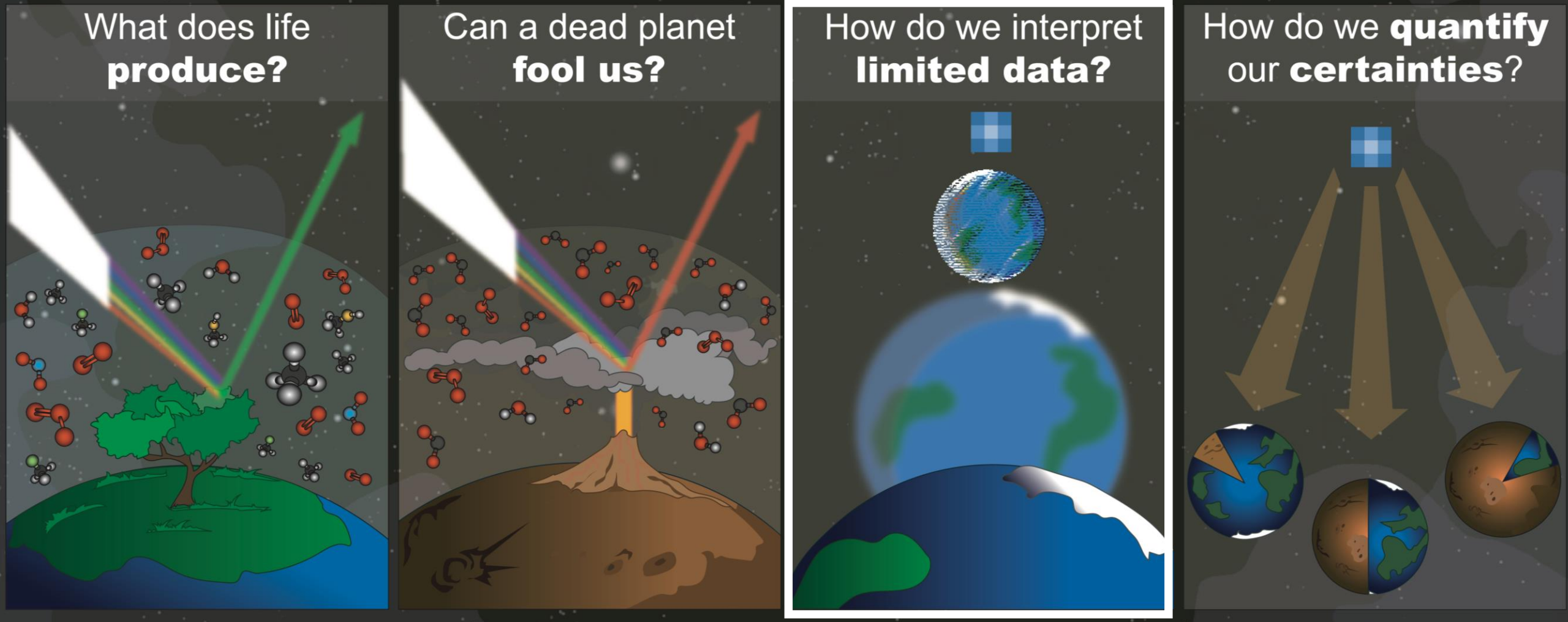
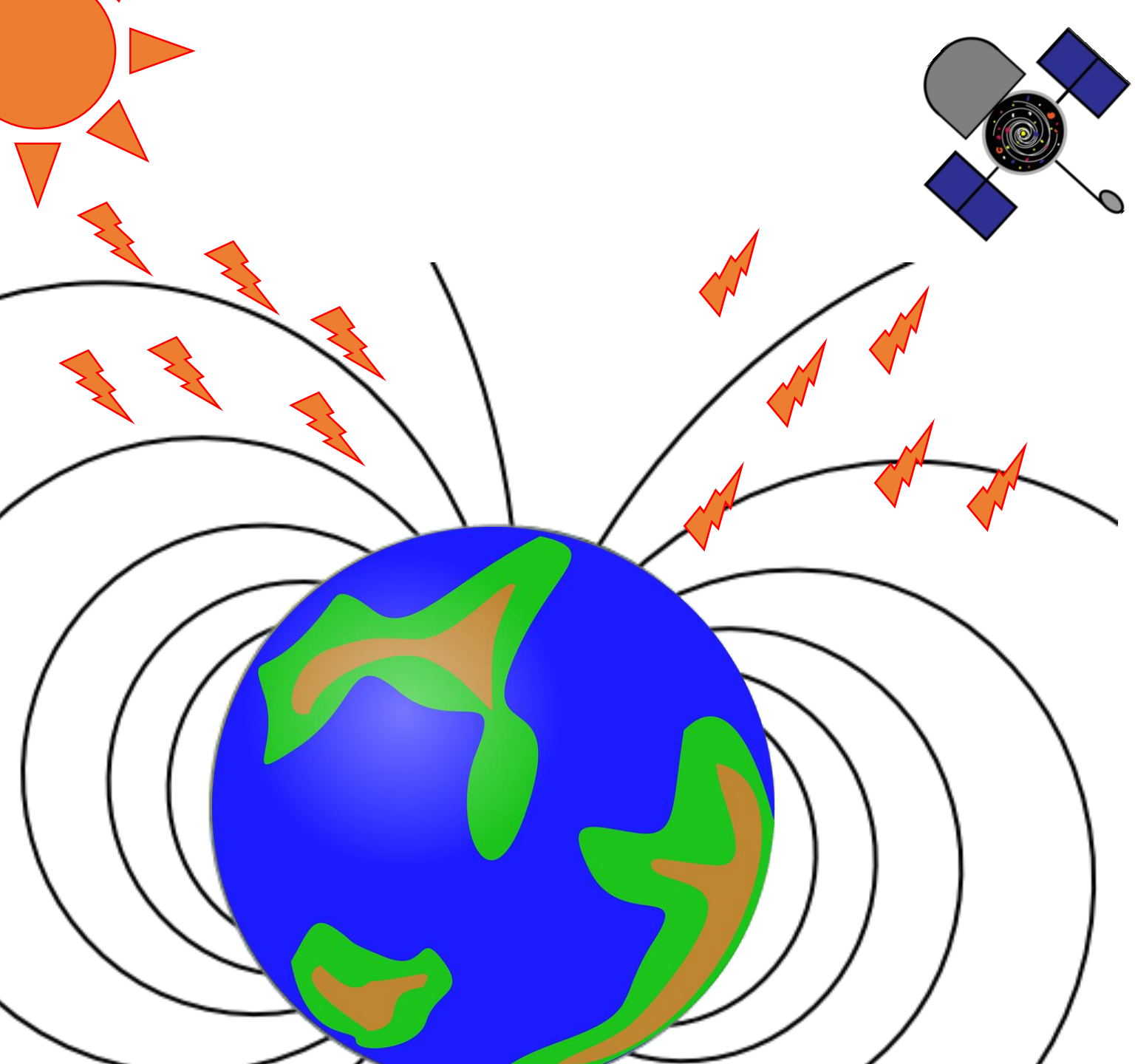
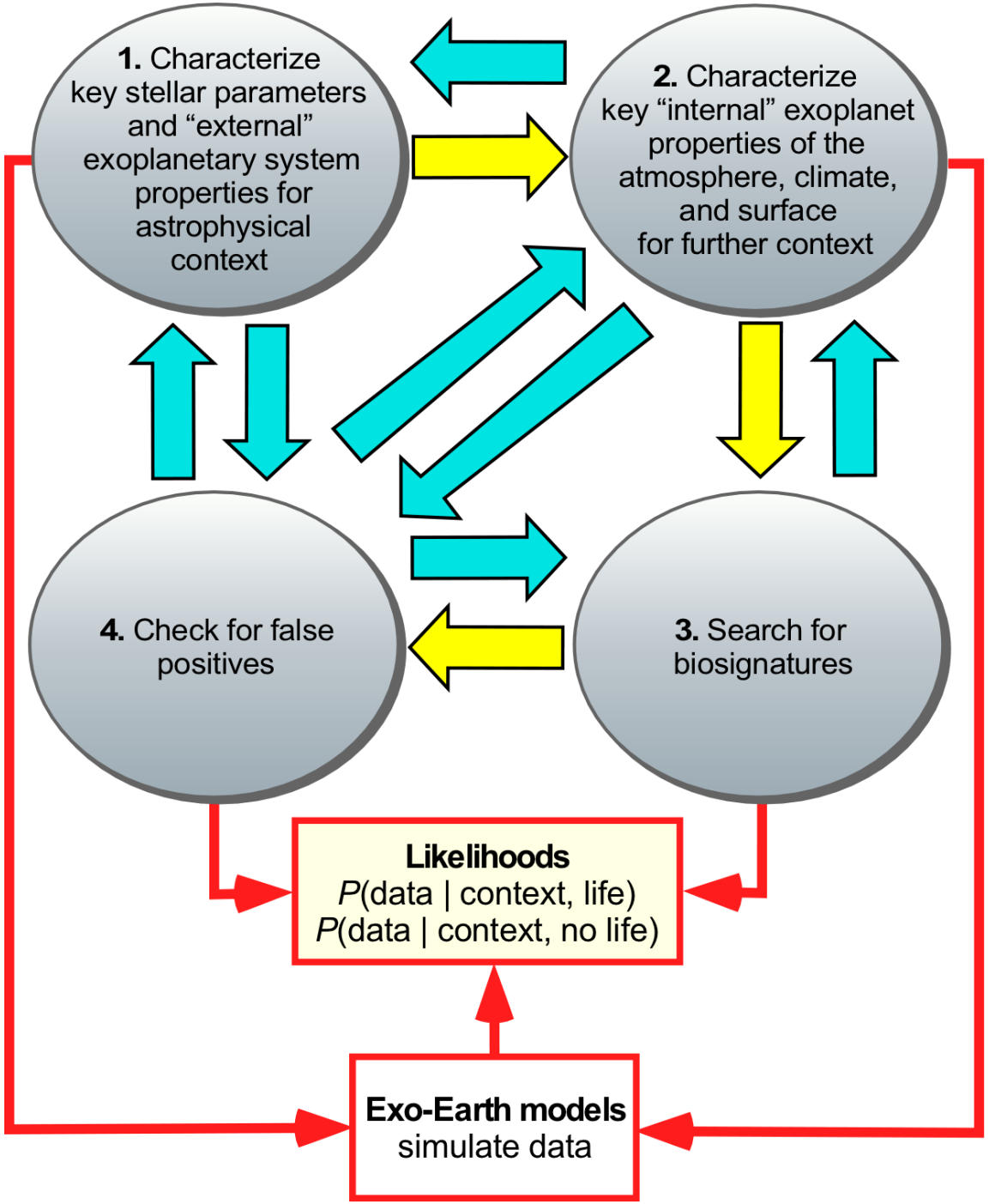


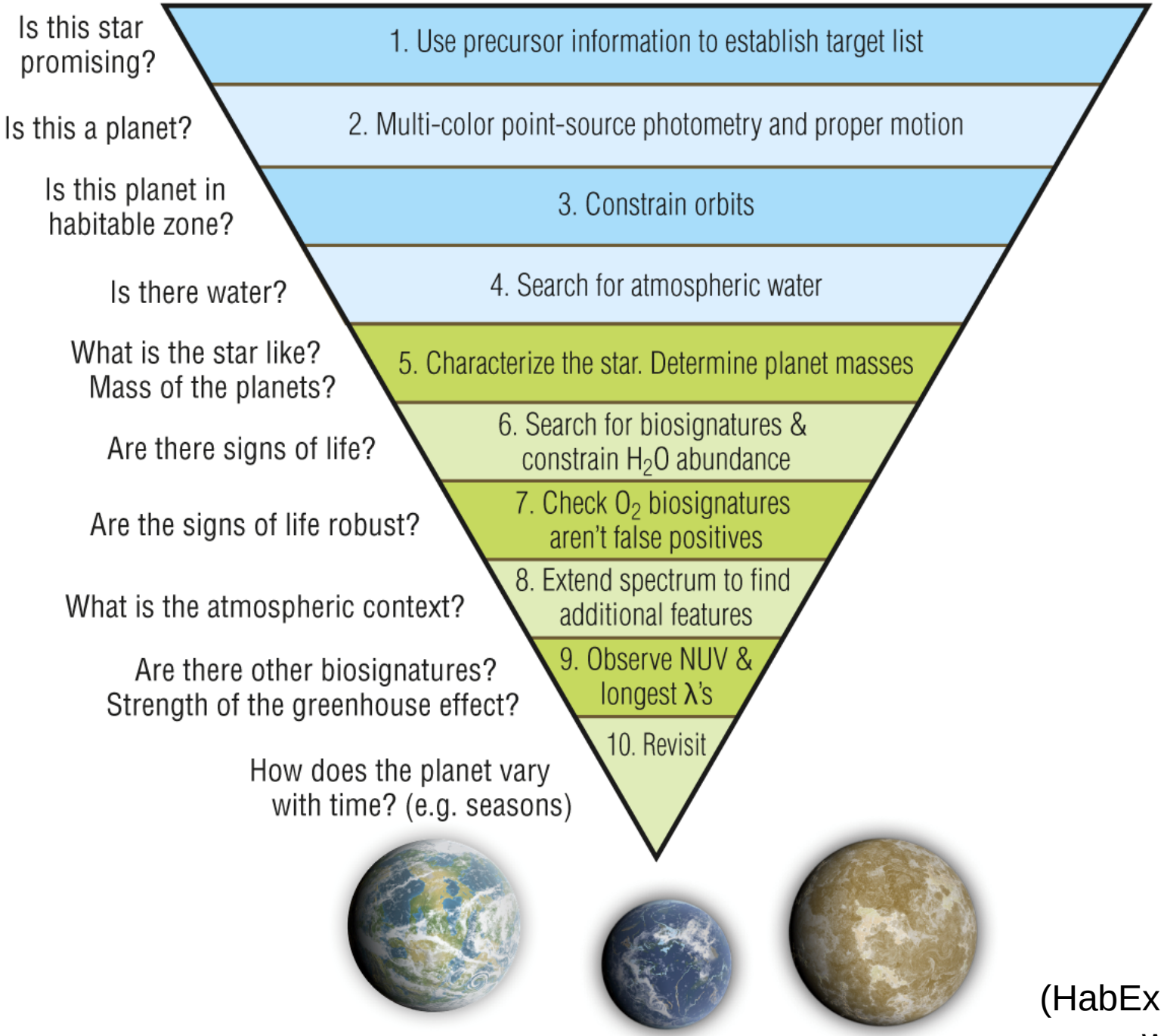
Figure by Aaron Gronstal
NExSS Biosignatures Workshop/SAG16



For exoplanets, the environmental context is beyond global.



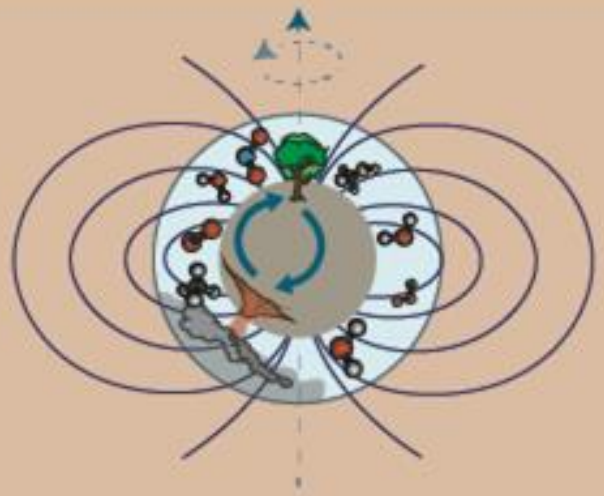
Catling+ 2017



LUVOIR interim report
(HabEx and OST have similar step-wise observation sequences)

Atmospheric Models, driven by host star and biology or geology

Global Climate Models and Planet Systems Models, driven by host star, that have bio-geochemistry and photochemical modules



Intermodel and intermodule comparisons of Global Climate Models, and Planet Systems Models

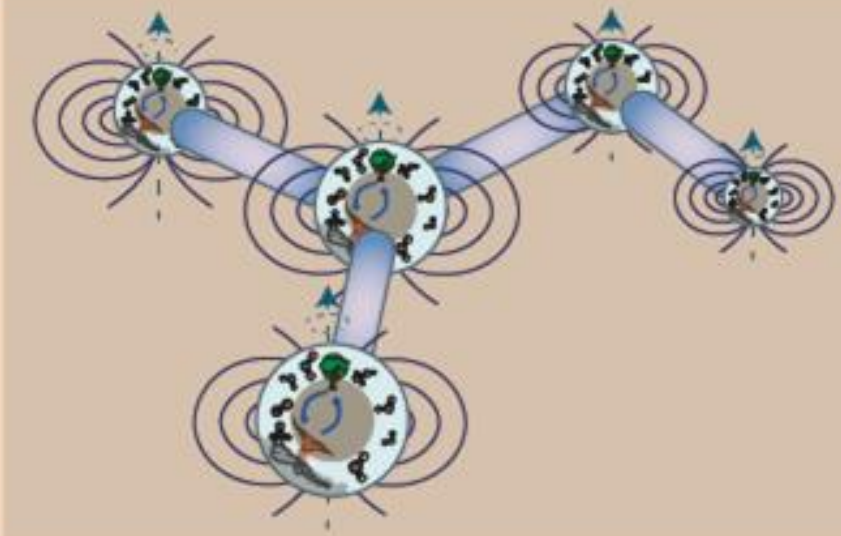


Figure by Aaron Gronstal
NExSS Biosignatures Workshop/SAG16

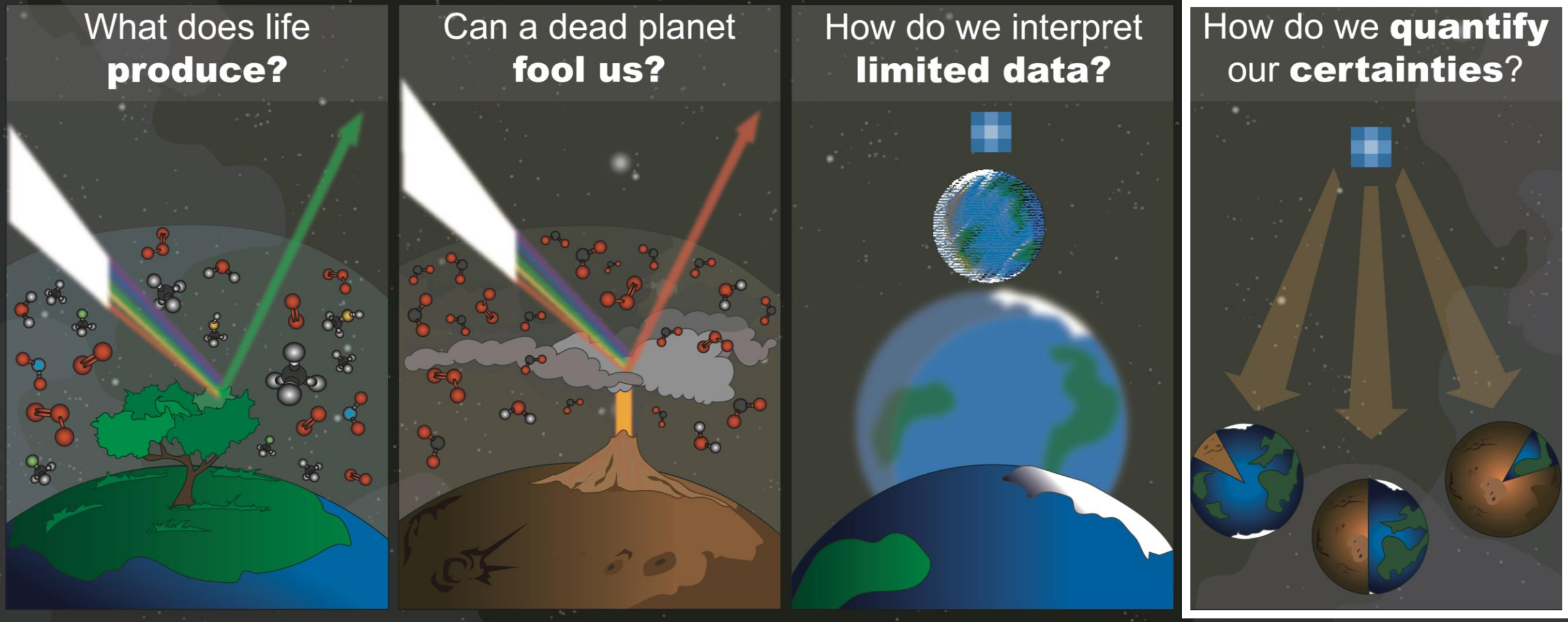
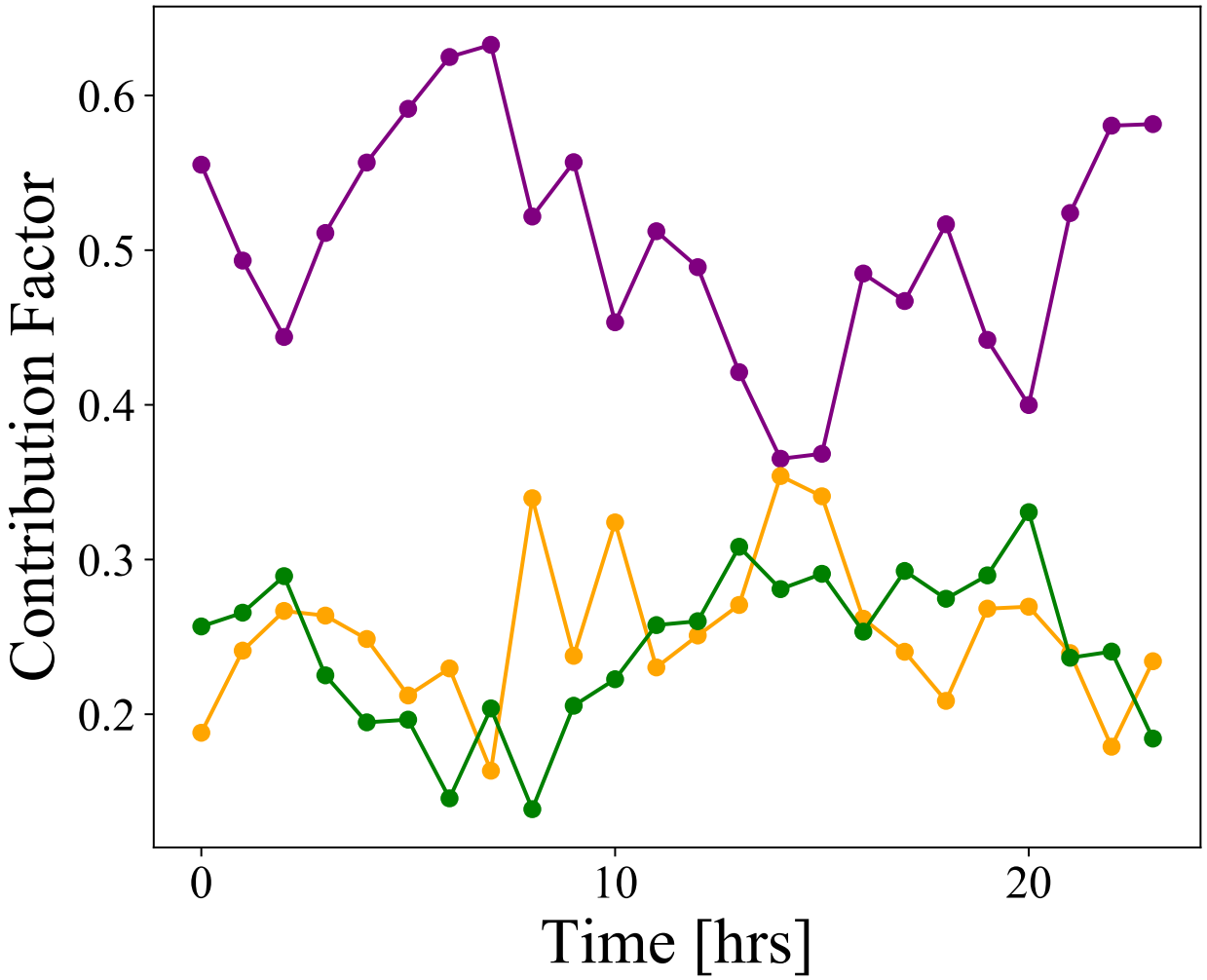


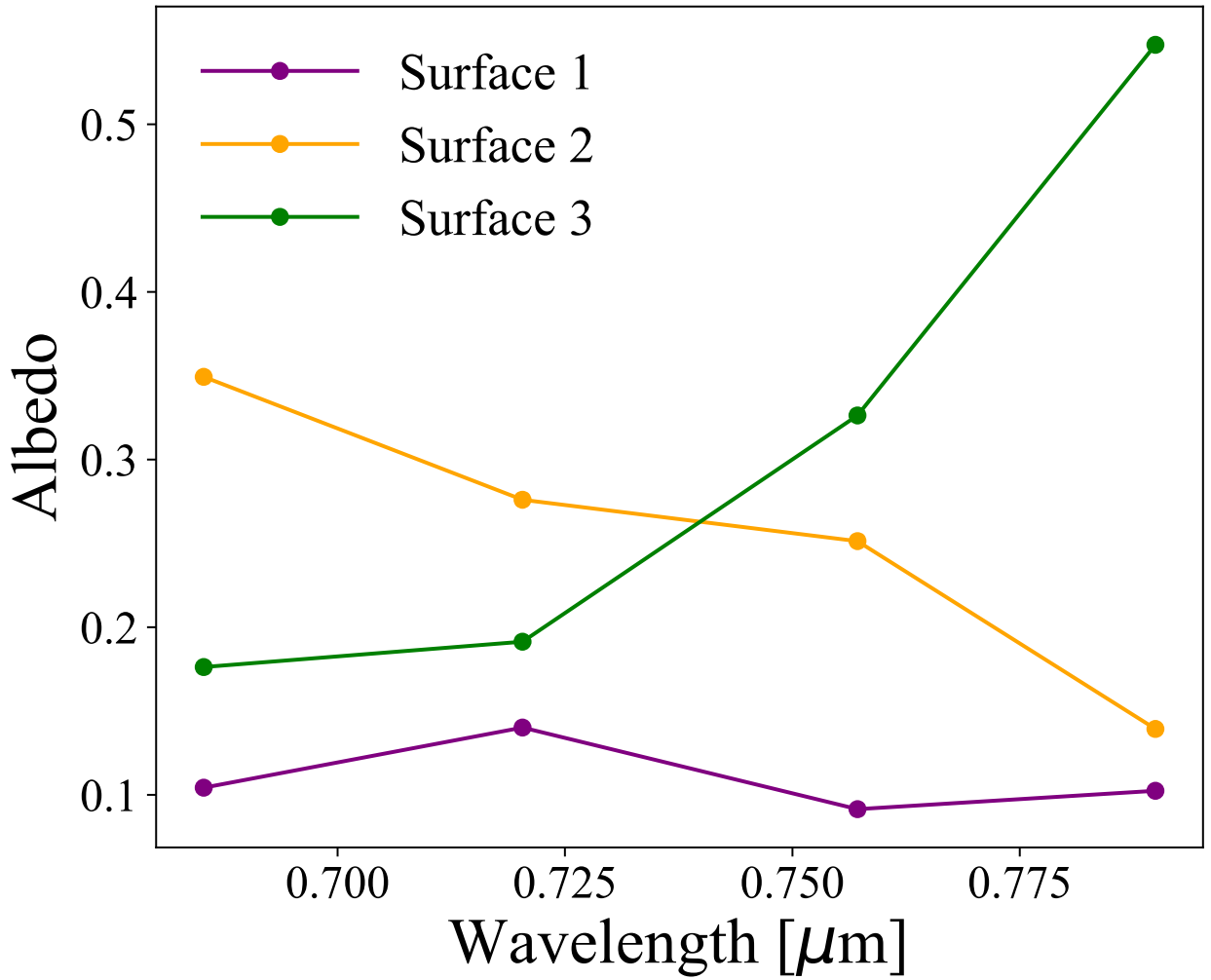
Figure by Aaron Gronstal
NExSS Biosignatures Workshop/SAG16

Confidence level for detection of life	**Posterior Probability *P*(life| data, context)**	**Evidence**
Level 1: Very likely inhabited	90-100%	Multiple lines of evidence for life. Given current understanding of planetary processes, no known abiotic process can plausibly explain all observed features.
Level 2: Likely inhabited	66-100%	The body of evidence is consistent with the presence of life.
Level 3: About as likely as not inhabited (inconclusive)	33–66%	Some evidence for life, but insufficient contextual information to draw a definitive conclusion because plausible alternative abiotic explanations cannot be ruled out.

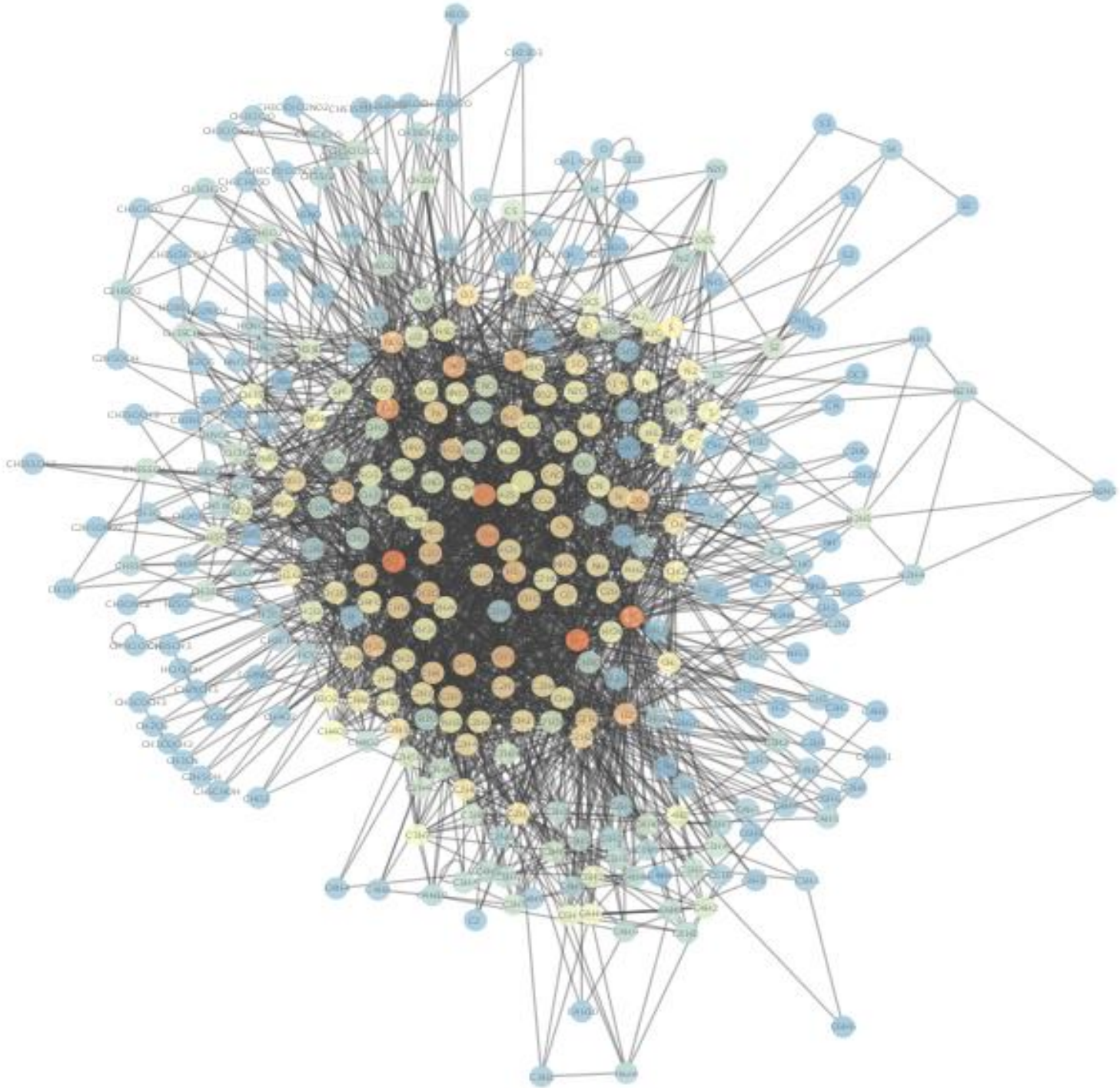
Catling+ 2017

vegetation detection w/30-m space telescope

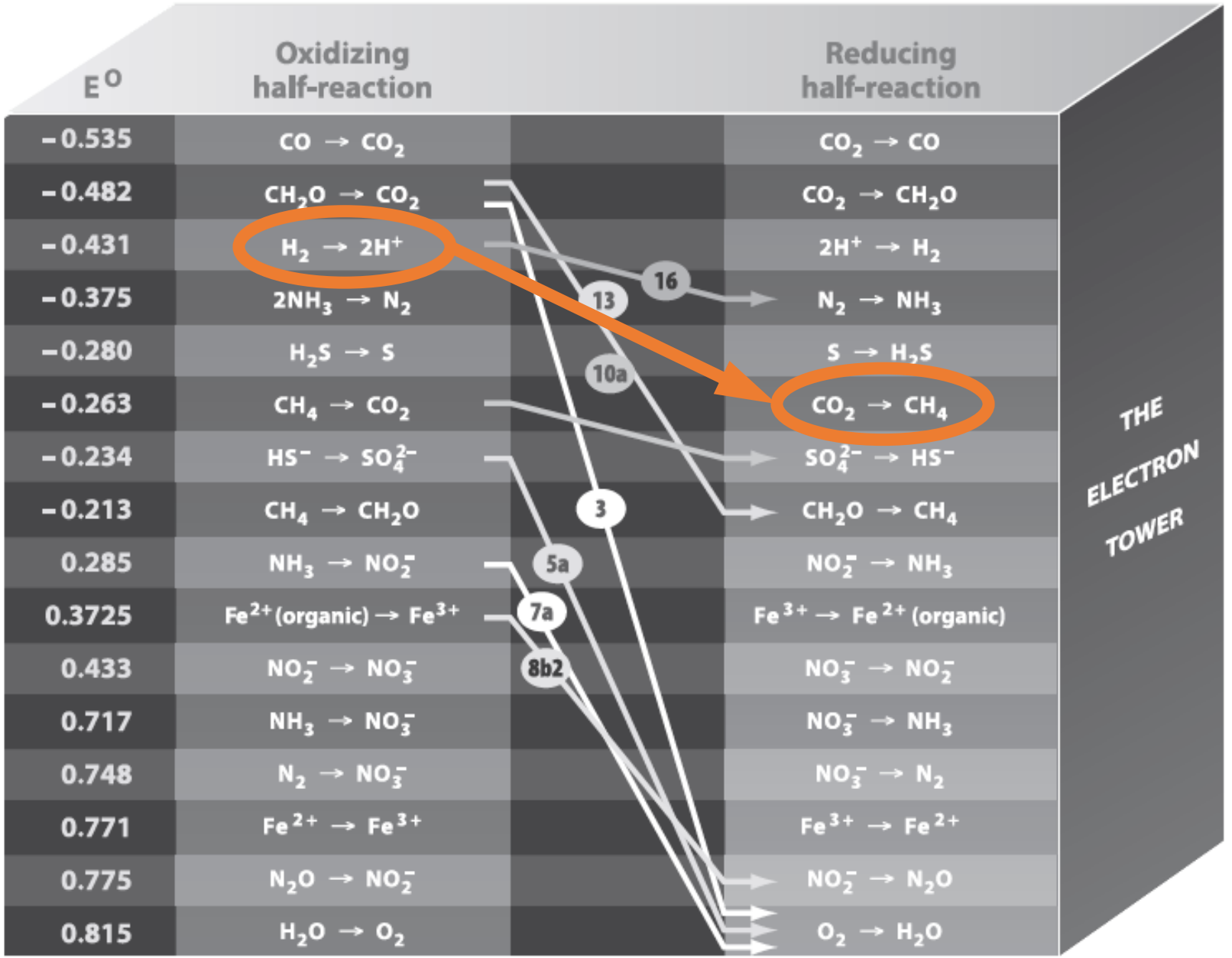




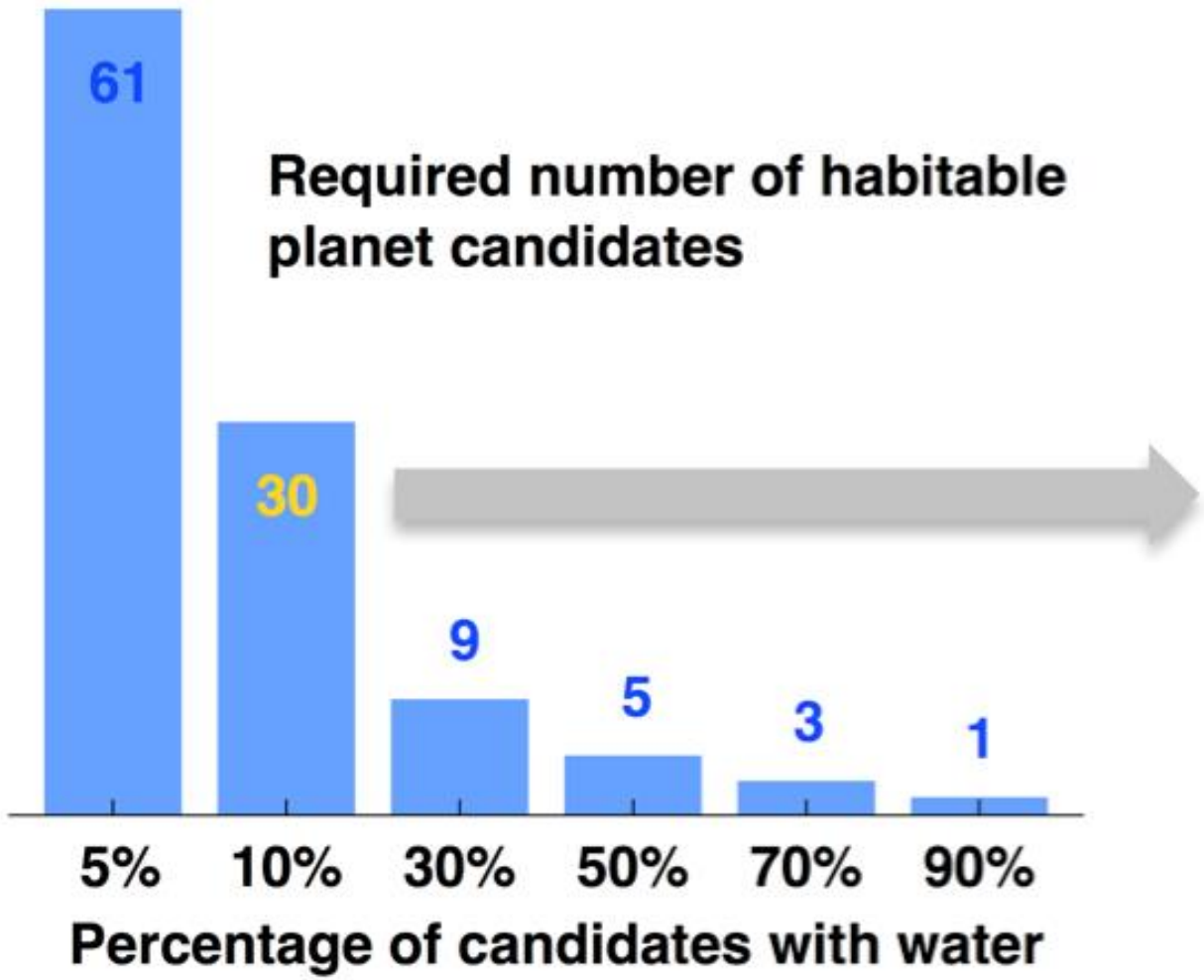
Simulations and figure
fromJacob Lustig-Yaeger

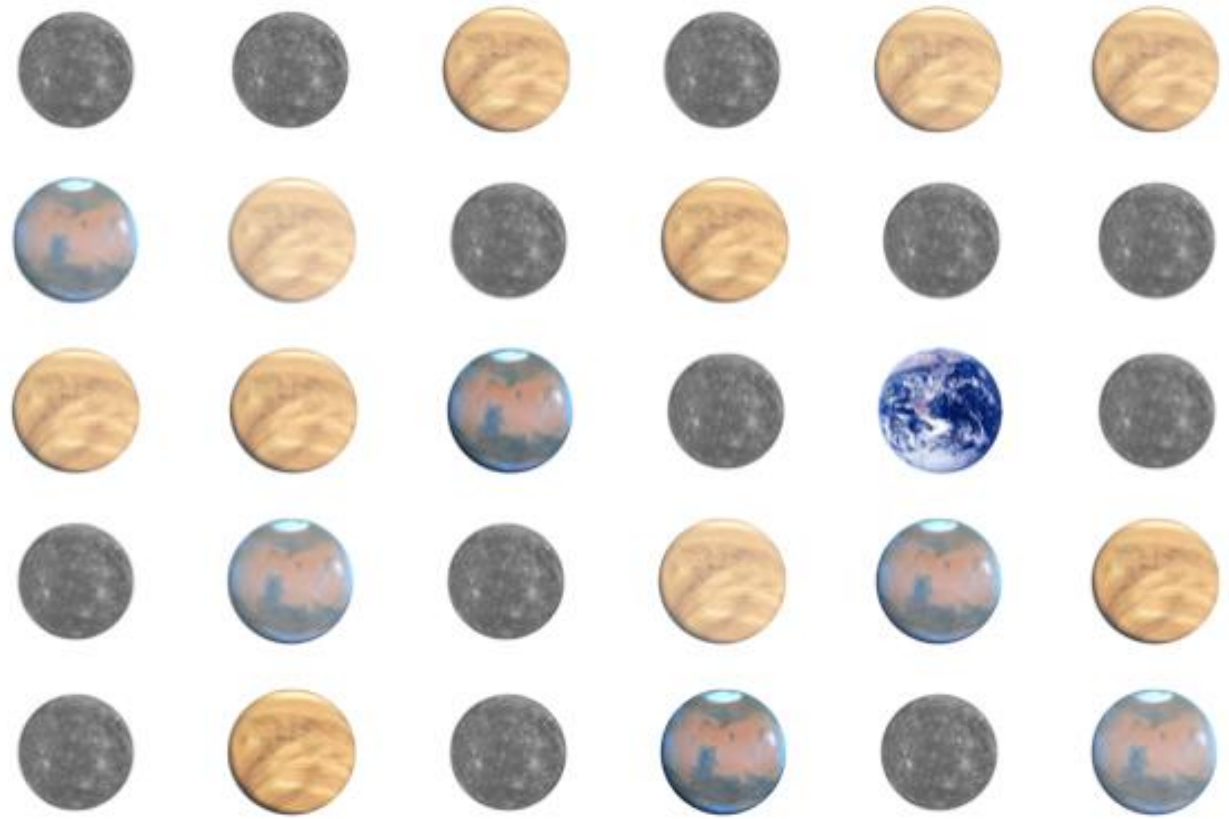


Walker+ 2017


E°
Oxidizing half-reaction
Reducing half-reaction
−0.535
CO → CO2
CO2 → CO
−0.482
CH2O → CO2
CO2 → CH2O
−0.431
H2 → 2H+
2H+ → H2
−0.375
2NH3 → N2
N2 → NH3
−0.280
H2S → S
S → H2S
−0.263
CH4 → CO2
CO2 → CH4
−0.234
HS− → SO4 2−
SO4 2− → HS−
−0.213
CH4 → CH2O
CH2O → CH4
0.285
NH3 → NO2−
NO2− → NH3
0.3725
Fe2+ (organic) → Fe3+
Fe3+ → Fe2+ (organic)
0.433
NO2− → NO3−
NO3− → NO2−
0.717
NH3 → NO3−
NO3− → NH3
0.748
N2 → NO3−
NO3− → N2
0.771
Fe2+ → Fe3+
Fe3+ → Fe2+
0.775
N2O → NO2−
NO2− → N2O
0.815
H2O → O2
O2 → H2O
16
13
10a
3
5a
7a
8b2
THE ELECTRON TOWER

Seager+ 2012





LUVOIR interim report

An abbreviated wish-list

- More complete incorporation of biological understanding into the field
- Models of abiotic processes under not-Earth-like conditions
- Evaluation of potential new biosignatures, and their false positives
- Sustained support of lab measurements of known and potential biosignatures
- Development/support for 3-D general circulation models, including chemistry
- Expansion of 1D models to include subsurface, surface (ocean, biology, geochemistry), atmospheric, and escape processes
- More accounting of model uncertainties, in general
- Quantitative biosignatures, and the adoption of statistical frameworks (e.g., Bayesian) to utilize them.
- *The interdisciplinary "glue" to make the above possible.*