Phase Report

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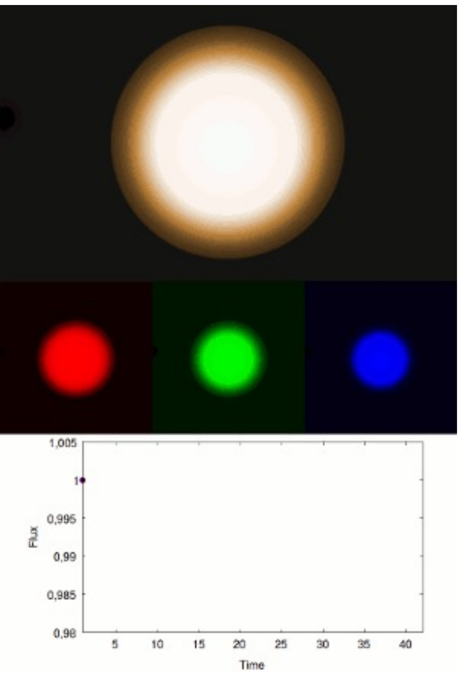
How do we find out if life exists in the universe?



Schrödinger states that life is a non-equilibrium system that feeds upon free energy and contains the instructions for its own self-replication, in what Schrödinger termed a molecular ‘codescript’.

We can observe the presence of chemical imbalances in a planet's atmosphere to confirm the presence of life.

JWST allows us to do this.

The chemical imbalances in the planetary atmosphere are reflected in certain molecules in the atmosphere, which have an unusual abundance

These molecules are called biosignature and include CH_4, CO_2, CO, and H_2O.

Currently, these biosiganture can only be detected by JWST, and the observability of biosignature on different planets becomes an important issue due to the expensive cost of JWST and the limited time of use.

The purpose of this project is to explore the observability of biosignature on different planets.

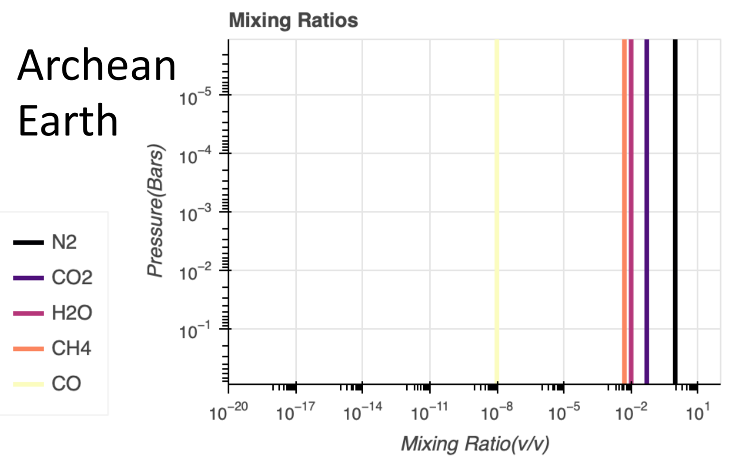
Tasks for this phase

- Task 1
  - Reproduce the main results from https://doi.org/10.1093/mnras/stab3383 (Mikal-Evans, Thomas. "Detecting the proposed CH4–CO2 biosignature pair with the James Webb Space Telescope: TRAPPIST-1e and the effect of cloud/haze.")
- Task 2
  - Repeat the process of task 1 for Trappist-1e in the Modern Earth atmosphere
- Task 3
  - Based on the results of task 1&2, calculate SNR and give the elemental observability ranking of Trappist-1e in Archean atmosphere (by JWST)

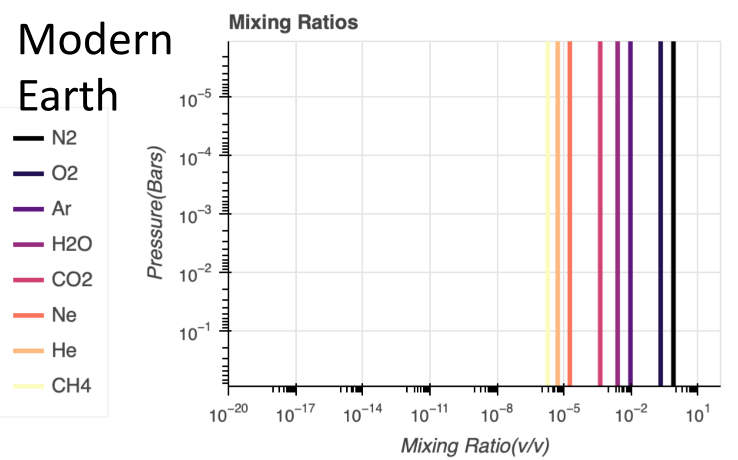
Setting

Molecular abundance (VMR)

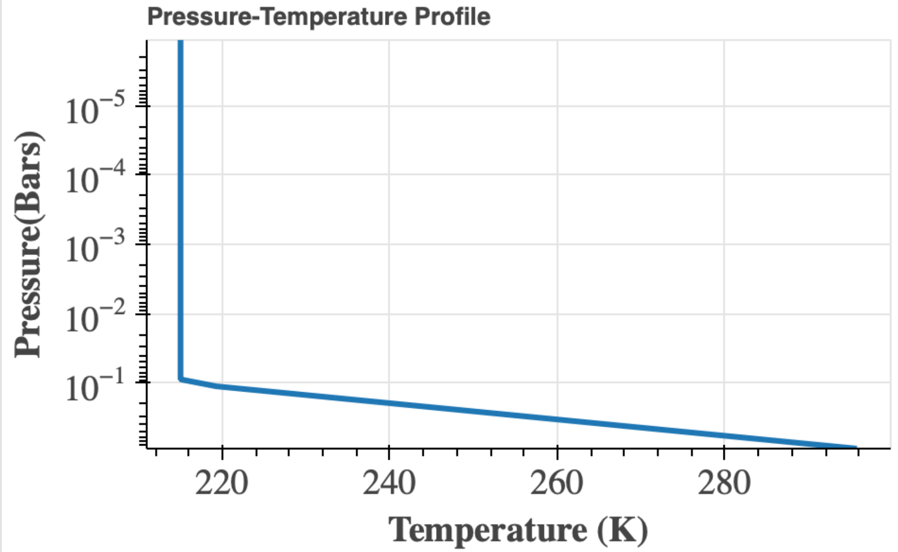
Archean Earth



Modern Earth

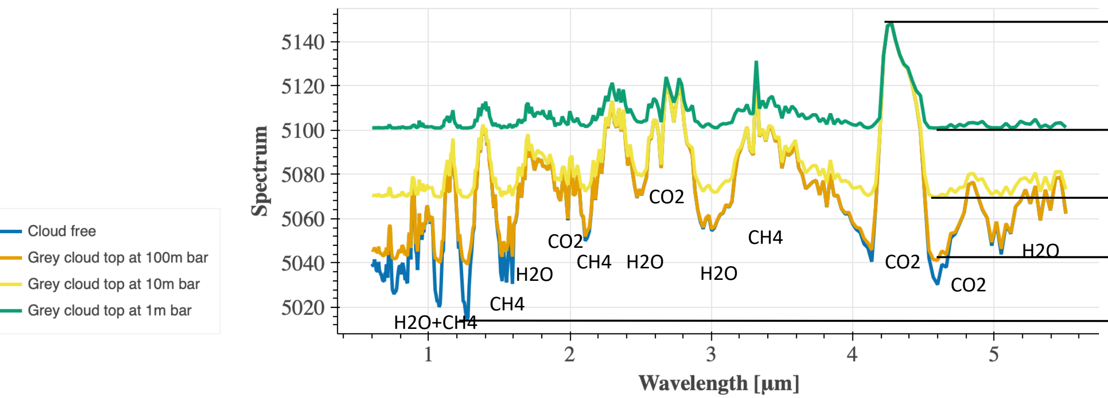


P-T Profile



TASK 1.1 Reproduce the spectra under different cloud layers from Evans' paper.

SD: Signal Difference(from top to bottom)



Max Value: 5148

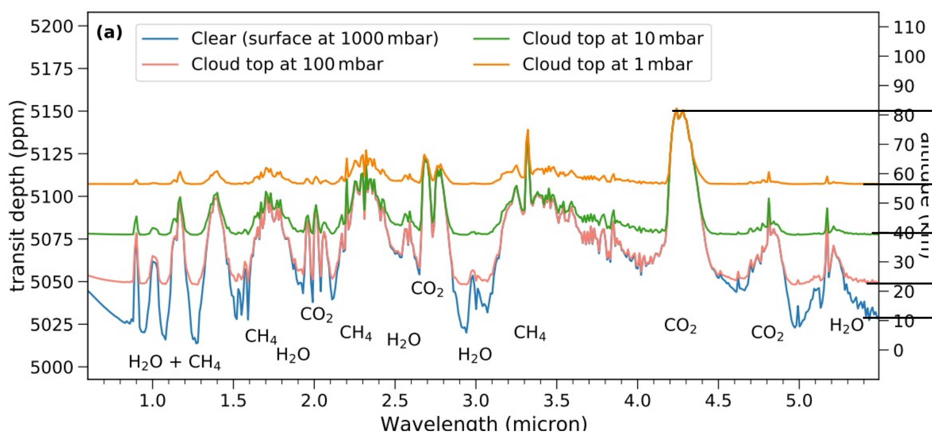
1 mbar: SD=47

10 mbar: SD=78

100 mbar: SD=108

Cloud Free: SD=133

Spectrum generated by *PICASO*



Max Value: 5150

1 mbar: SD= 45

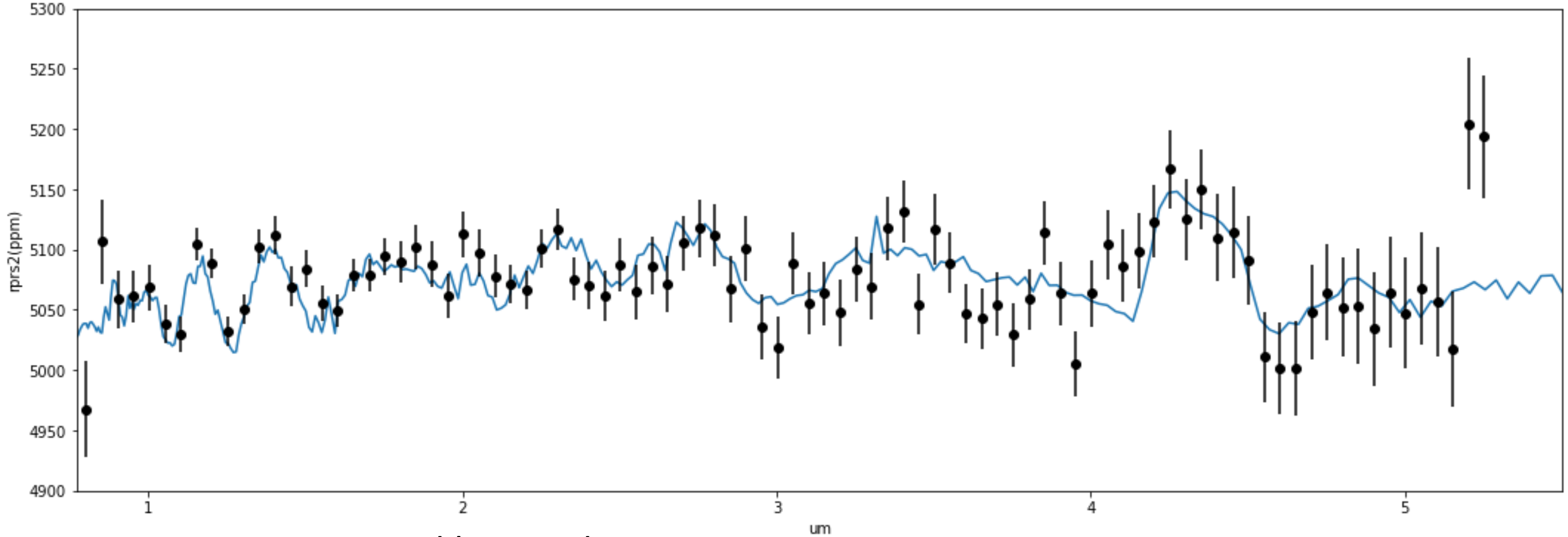
10 mbar: SD=75

100 mbar: SD =105

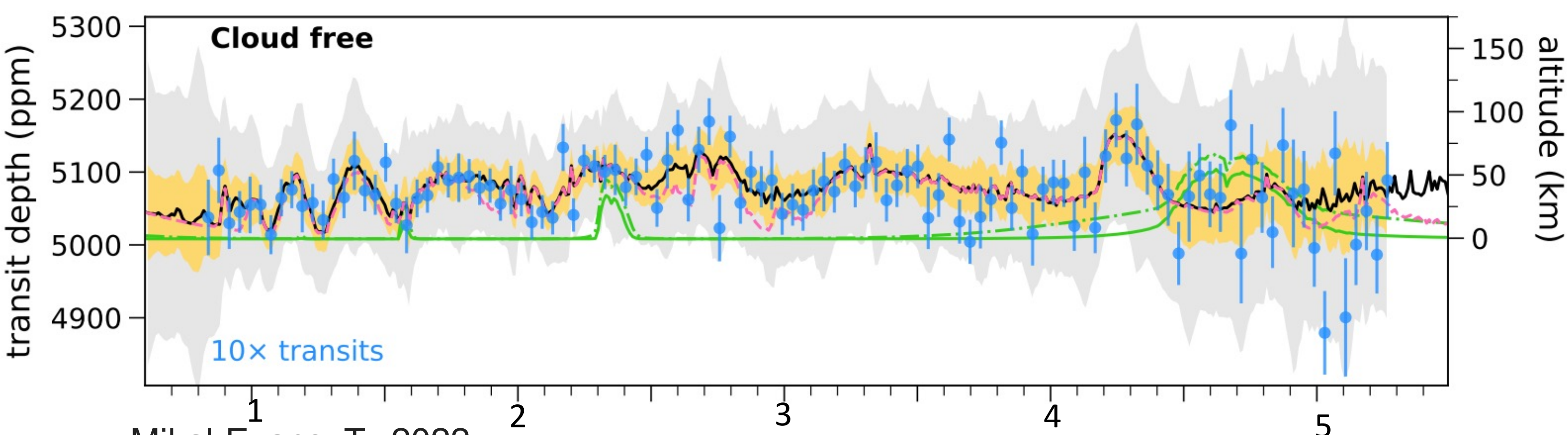
Cloud Free: SD=135

Mikal-Evans, T., 2022.

TASK 1.2 Reproduce the predict spectrum of the observation of JWST in Evans' paper.



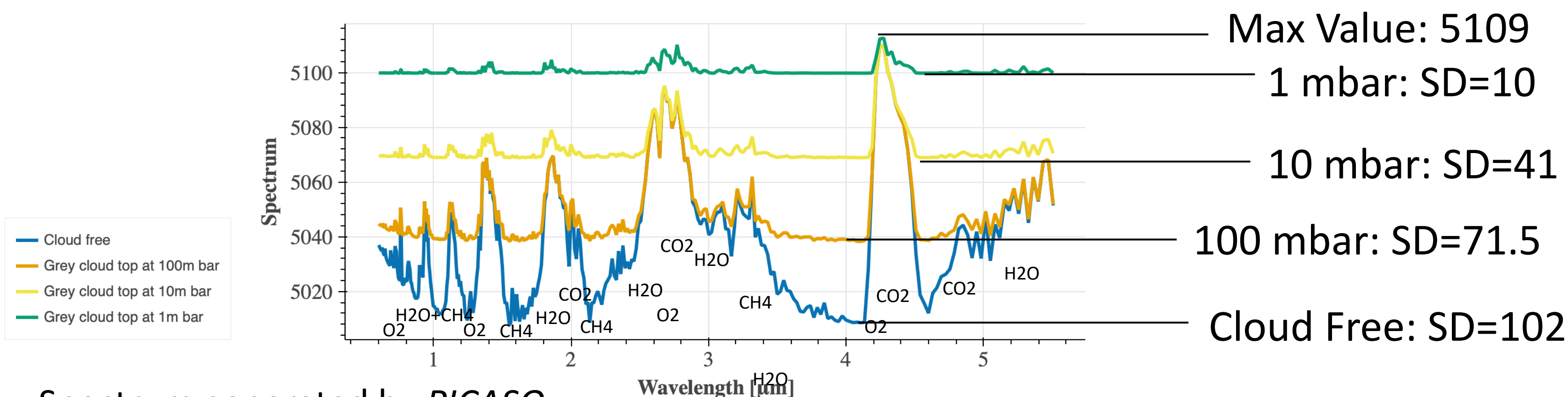
Spectrum generated by *PandExo*



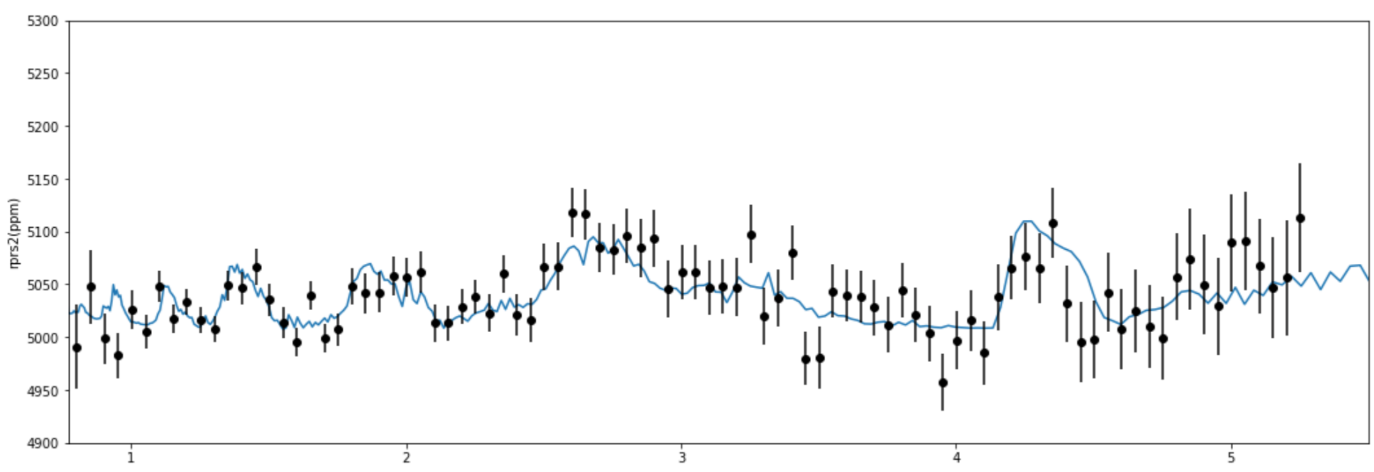
Mikal-Evans, T., 2022.

TASK 2 Obtain the spectra of different cloud layers in the modern earth and predict spectrum of JWST observations

SD: Signal Difference(from top to bottom)



Spectrum generated by *PICASO*

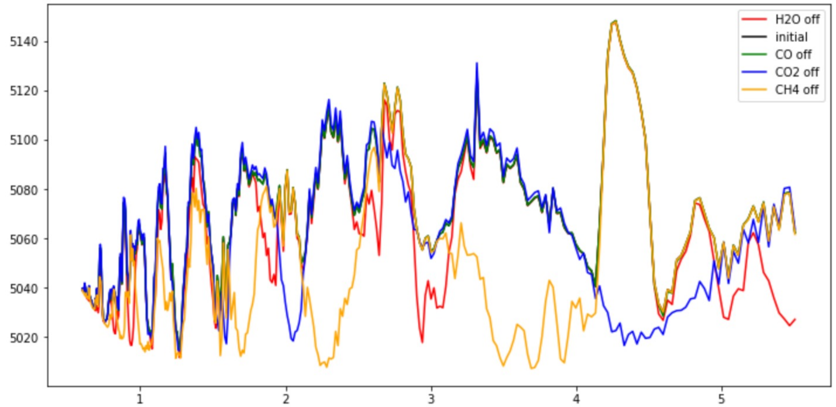


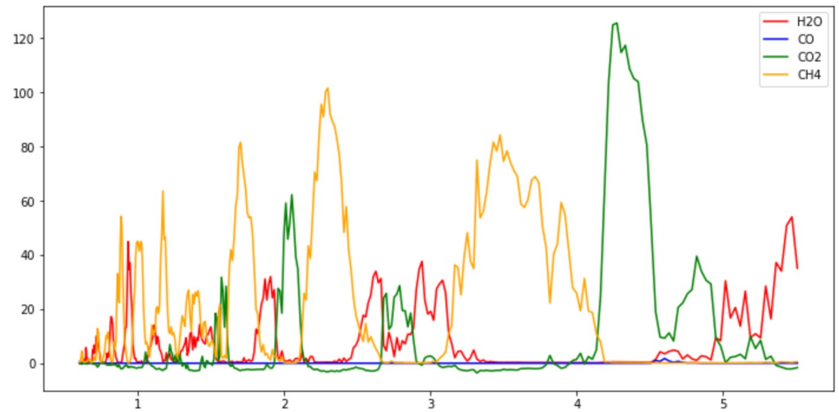
Spectrum generated by *PandExo*

TASK 3.1 Find the feature wavelength of biosignature

Method for finding the feature wavelength:
(Phillips, et al. 2021.)

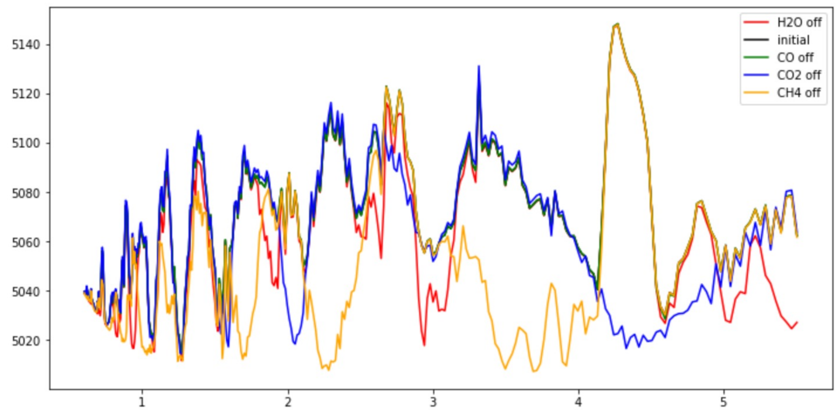
Feature curve of H2O = The curve of initial - The curve of H2O off

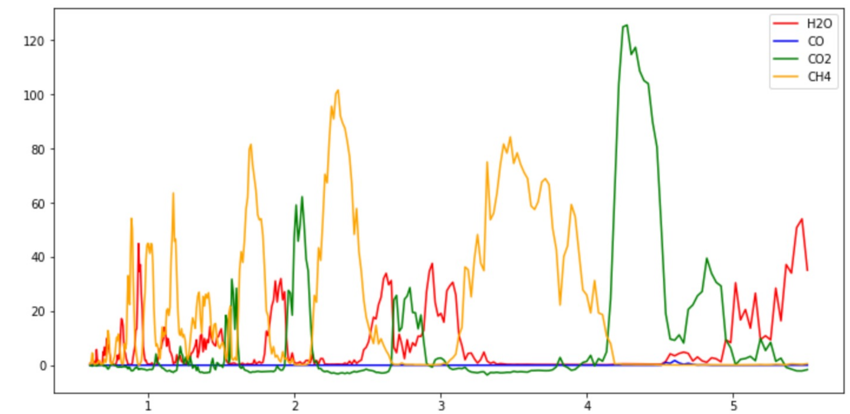




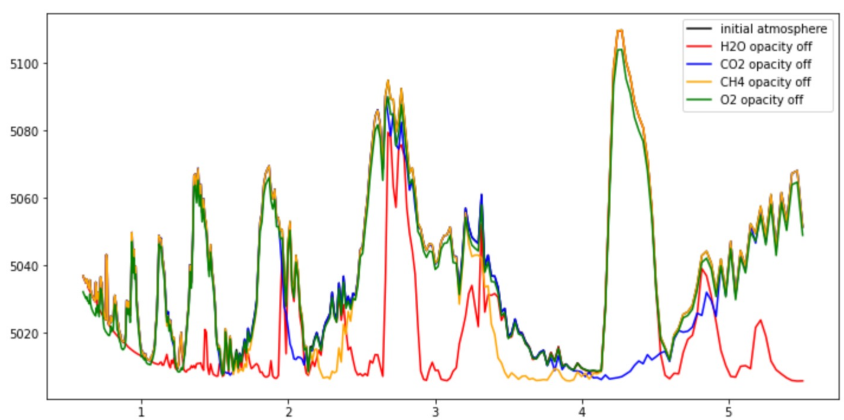
TASK 3.1 Find the feature wavelength of biosignature

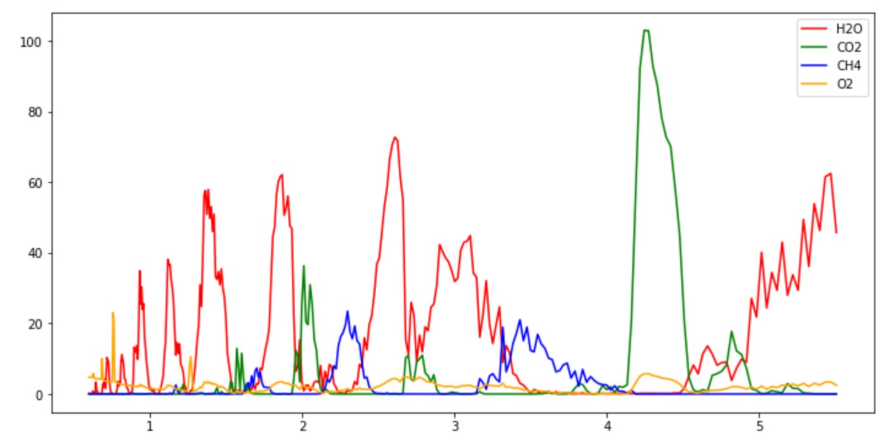
Archean Earth





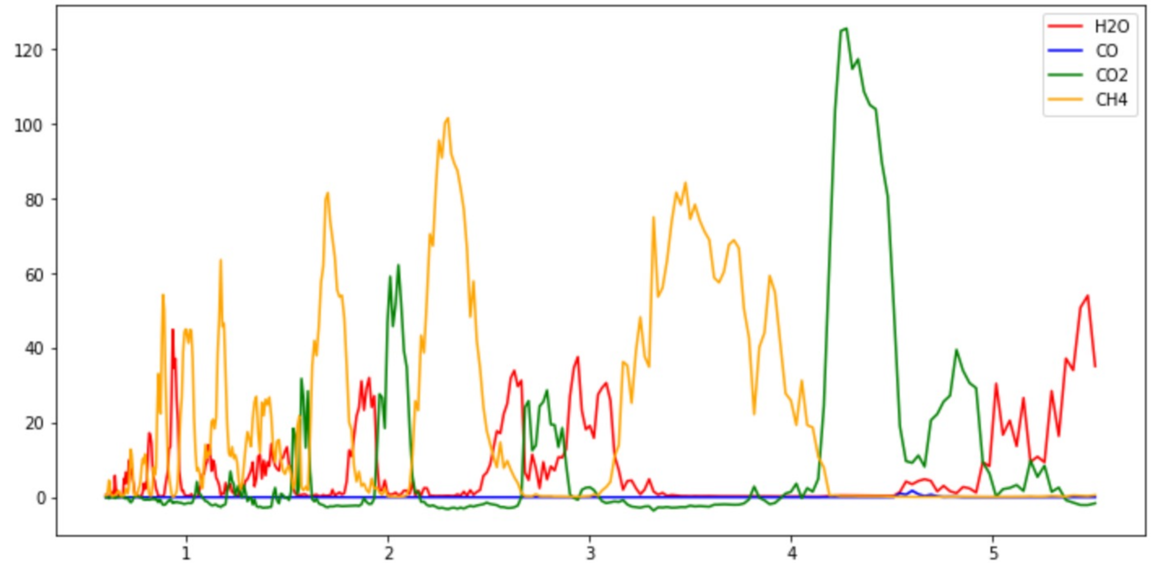
Modern Earth





TASK 3.1 Find the feature wavelength of biosignature

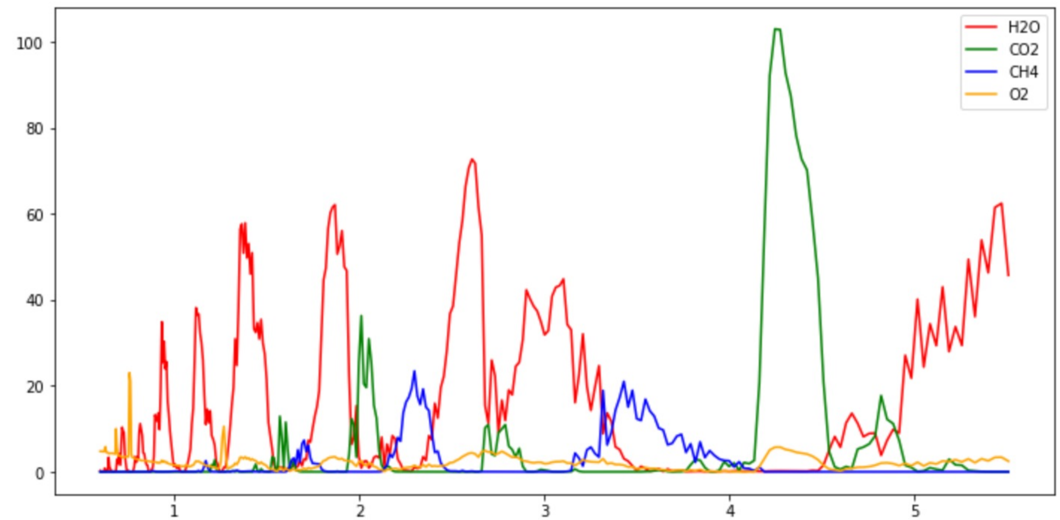
Archean Earth



Elements	Feature Wavelength (um)					
CO	4.60					
CH4	0.85-0.90	0.97-1.06	1.12-1.20	1.65-1.79	2.2-2.41	3.23-3.95
CO2	1.56-1.61	1.96-2.10	2.67-2.87	4.18-4.49	4.69-4.93	
H2O	0.93-0.96	1.83-1.94	2.54-2.67	2.89-3.11	5.00-5.17	5.3-5.5

TASK 3.1 Find the feature wavelength of biosignature

Modern Earth



Elements	Feature Wavelength (um)						
O2	0.76	1.27	2.52-2.90	4.18-4.45			
CH4	1.65-1.74	2.23-2.38	3.31-3.62				
CO2	1.57-1.62	1.99-2.07	2.67-2.71	4.18-4.47	4.78-4.90		
H2O	0.93-0.97	1.11-1.17	1.33-1.48	1.80-1.94	2.47-2.67	2.83-3.30	4.90-5.50

TASK 3.2 Calculating SNR

Equation of SNR

$$S/N = \frac{\overbrace{(R_p/R_\star)^2}^{A} - \overbrace{\overline{(R_p/R_\star)^2}}^{B}}{\underbrace{\sigma_{(R_p/R_\star)^2}}_{C}},$$

Equation of <S/N>

$$<S/N> = \sqrt{\sum_i S/N_i^2}$$

(Phillips, et al. 2021.)

SNR: The higher the SNR, the more observable the biosignature is in the relevant band.

Term A
Transmission Signal
Come from PICASO

Term B
Minimum $(R_p/R_\star)^2$
Come from PICASO

Term C
Uncertainty
Come from PandExo

TASK 3.2 Example of calculating SNR

$$S/N = \frac{(R_p/R_\star)^2 - \overline{(R_p/R_\star)^2}}{\sigma_{(R_p/R_\star)^2}},$$

$$<S/N> = \sqrt{\sum_i S/N_i^2}$$

For Modern Earth, $\overline{(R_p/R_\star)^2}$ =5009.08

2.23-2.38				
wavelength	$(\frac{R_p}{R_*})^2$	$\sigma_{(\frac{R_p}{R_*})^2}$	S/N	<S/N>
2.25	5044.72	30.04	1.19	
2.26	5036.48	30.25	0.91	
2.28	5027.09	31.04	0.58	
2.30	4999.31	32.06	0	3.60
2.32	5028.89	32.64	0.61	
2.33	5093.09	32.74	2.57	
2.35	5060.08	32.79	1.56	
2.37	5043.34	33.48	1.02	

1.65-1.74				
wavelength	$(\frac{R_p}{R_*})^2$	$\sigma_{(\frac{R_p}{R_*})^2}$	S/N	<S/N>
1.66	5060.83	22.51	2.30	
1.68	5010.81	22.52	0.08	2.35
1.70	4976.63	23.04	0.00	
1.72	5020.70	24.06	0.48	

<S/N> of CH4 (from 0.6-5.5 um, Modern Earth) :

$$< S/N >_{total} = (< S/N >_{2.23-2.38} + < S/N >_{1.65-1.74} + < S/N >_{3.31-3.62})^{1/2}$$

=5.91

TASK 3.3 SNR of biosignature in Archean Earth

CO2			
wavelength	<S/N>	$< S/N >_{total}$	Rank
4.69-4.93	9.26	36.21	1
4.18-4.49	20.32		
2.67-2.87	17.68		
1.96-2.10	18.55		
1.56-1.61	12.48		

H2O			
wavelength	<S/N>	$< S/N >_{total}$	Rank
5.3-5.5	3.26	31.90	2
5.00-5.17	6.25		
2.89-3.11	16.31		
2.54-2.67	17.74		
1.83-1.94	17.67		
0.93-0.96	8.87		

CH4			
wavelength	<S/N>	$< S/N >_{total}$	Rank
3.25-3.95	9.80	17.59	3
2.2-2.41	10.76		
1.65-1.70	7.78		
1.15-1.20	5.39		
0.97-1.06	1.86		
0.85-0.9	2.12		

CO			
wavelength	<S/N>	$< S/N >_{total}$	Rank
4.60	0.12	0.12	4

TASK 3.3 SNR of biosignature in Modern Earth

H2O			
wavelength	<S/N>	$< S/N >_{total}$	Rank
4.9-5.5	4.60		
2.83-3.30	7.06		
2.47-2.67	7.61		
1.80-1.94	4.32	13.66	1
1.33-1.48	5.07		
1.11-1.17	3.63		
0.93-0.97	0.43		

O2			
wavelength	<S/N>	$< S/N >_{total}$	Rank
4.18-4.45	4.72		
2.52-2.90	9.99	11.41	2
1.27	2.74		
0.76	0.80		

CO2			
wavelength	<S/N>	$< S/N >_{total}$	Rank
4.78-4.90	2.00		
4.18-4.47	4.72		
2.67-2.71	2.85	6.67	3
1.99-2.07	3.17		
1.57-1.62	0		

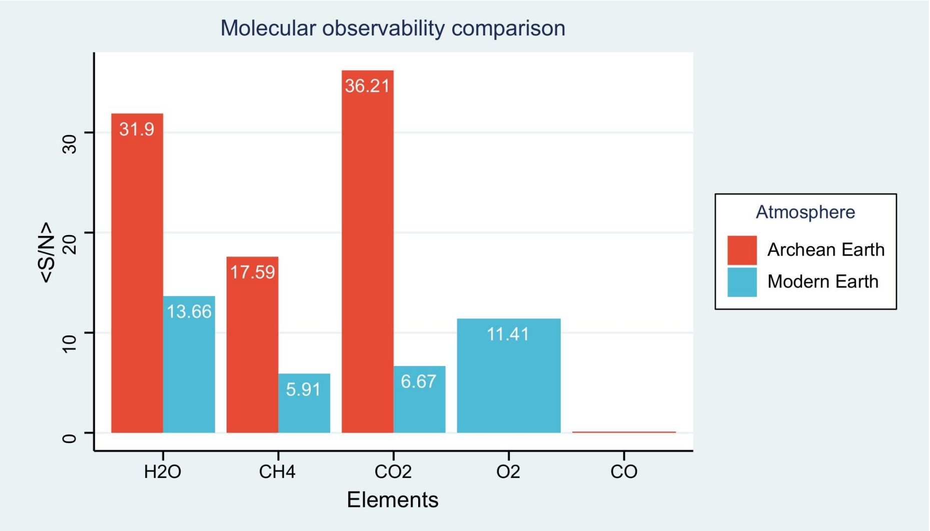
CH4			
wavelength	<S/N>	$< S/N >_{total}$	Rank
3.31-3.62	4.05		
2.23-2.38	3.60	5.91	4
1.65-1.74	2.35		

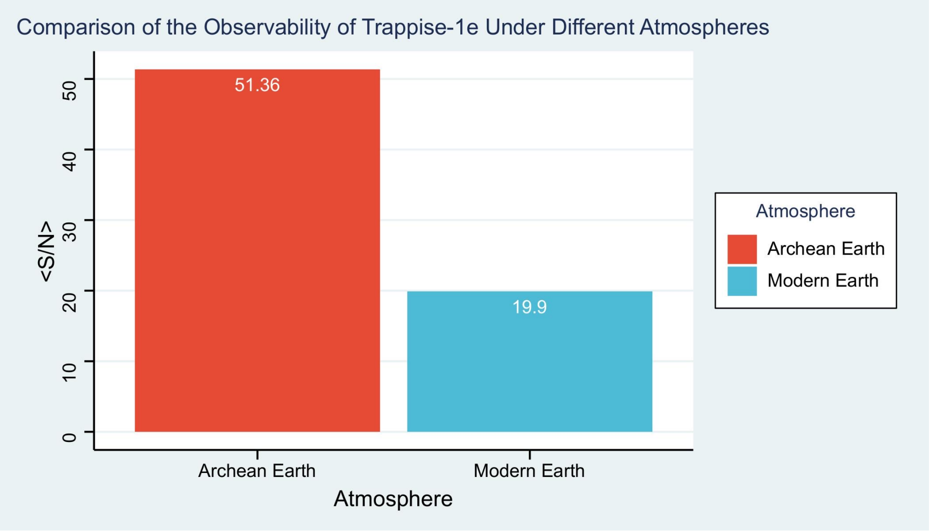
Analysis results

We can see that although O2 is not present in the atmosphere of Archean Earth, the rest of the biosignatures of Archean Earth are more observable than those of Modern Earth.

It is obvious that the total observability of Archean Earth is higher than Modern Earth.

Now we focus on Archean Earth

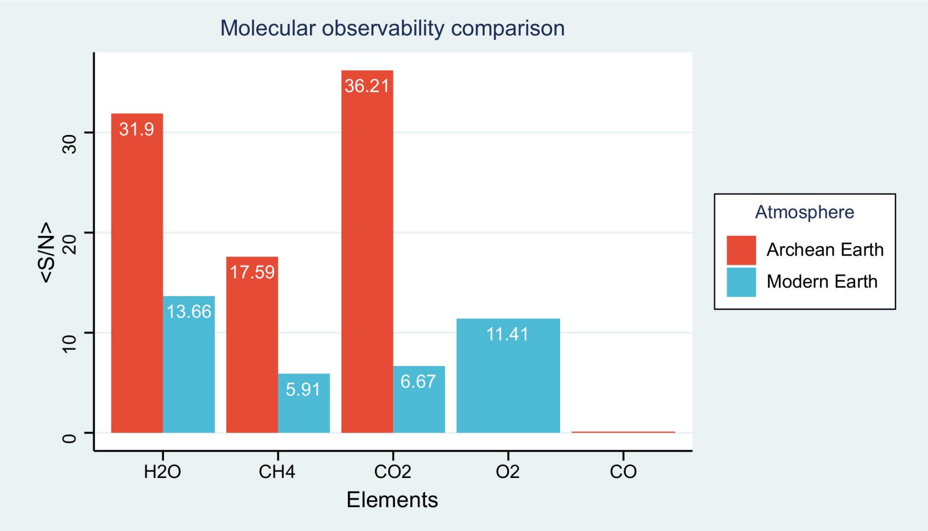




Analysis results

More specifically, how can we infer the existence of life from the presence of gases?

Krissansen Totton et al. states that the simultaneous presence of certain gases implies that life may exist.
e.g., CH4 and CO2 are present in large quantities at the same time

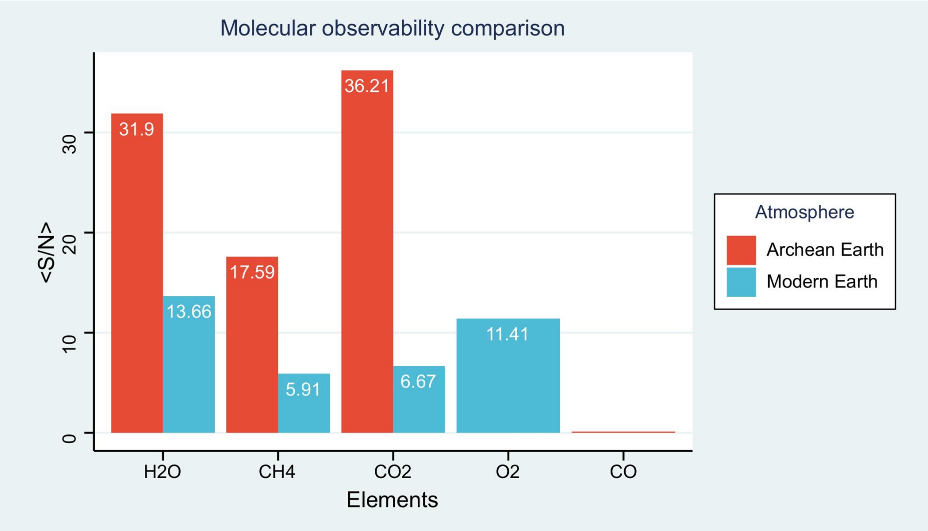


The presence of certain biosignature combinations may be far more important than other biosignatures.

Analysis results

It is important to explore the observability of these specific biosignature combinations.

Here, based on SNR, I define an equation to quantify the observable properties of certain gas combinations.



$$< S/N >_{\mathrm{pair}}{}^{2} = < S/N >_{total\ \mathrm{gas1}} \cdot < S/N >_{total\ gas2}$$

For Archean Earth, the pair <S/N> of CO2 and CH4 :

$$< S/N >_{\mathrm{pair}} = (31.9 \cdot 17.59)^{1/2}$$

=23.69

Report Over

THANK YOU!

Nest phase?

To be continued

All raw data are from
https://exoplanetarchive.ipac.caltech.edu/

The open-source software used in the process

PICASO

PandExo