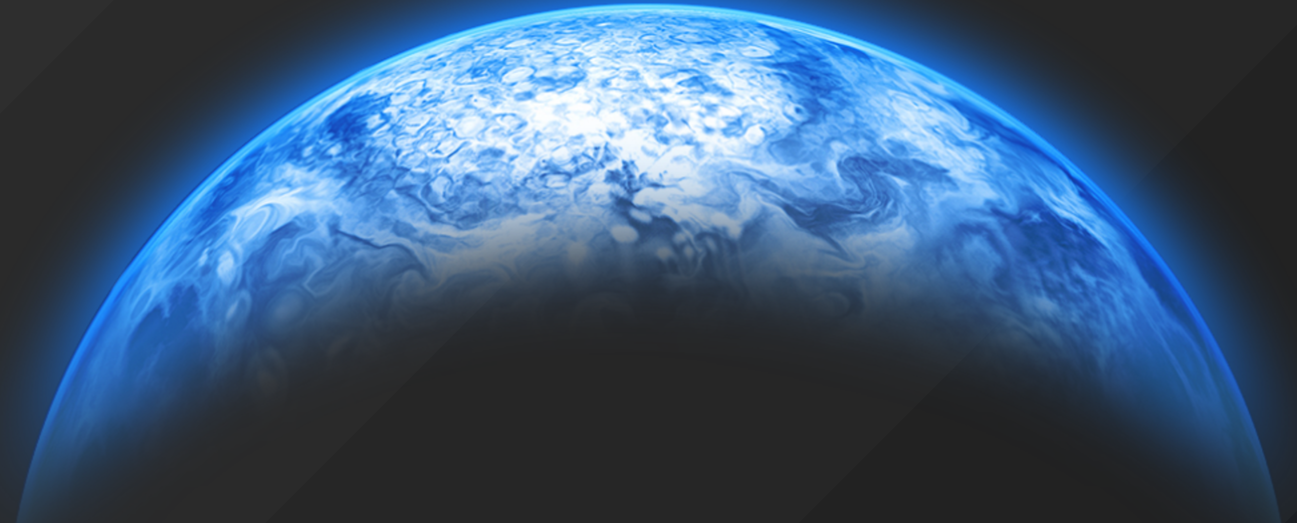

Diagnostic potential of the mid-infrared space interferometer LIFE for studying Earth analogs

Eleonora Alei
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Based on:

Alei, E.; Konrad, B. S.; Daniel Angerhausen; Grenfell, J. L.; Mollière, P.; Quanz, S. P.; Rugheimer, S.; Wunderlich, F. and the LIFE collaboration (LIFE V), submitted to A&A
https://arxiv.org/abs/2204.10041

What is LIFE

www.life-space-mission.com

Our vision

LIFE shall obtain **thermal emission spectra** with sufficient spectral resolution, wavelength coverage and sensitivity to investigate at **least 30 (requirement) / 50 (goal) extrasolar planets with radii between 0.5 and 1.5 Earth radii** and receiving between 0.35 and 1.7 times the insolation of the Earth in order to assess **their diversity, habitability and search for biomarkers**. The sample shall be roughly equally split between planets orbiting late **K to early M-type** stars and planets orbiting **late F to early K-type stars.**

See Mohan Ranganathan's poster about LIFE & NICE!

Roadmap

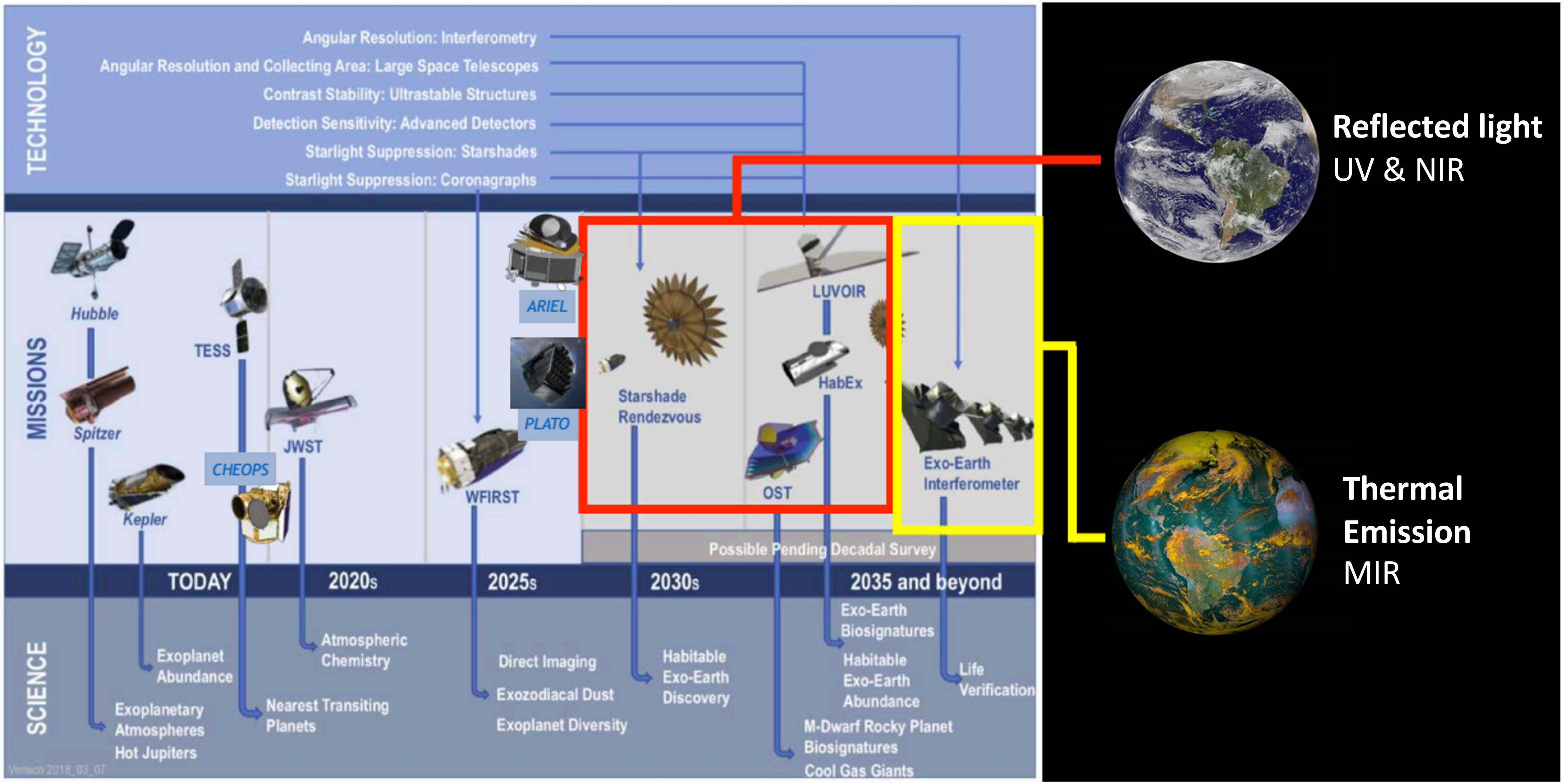


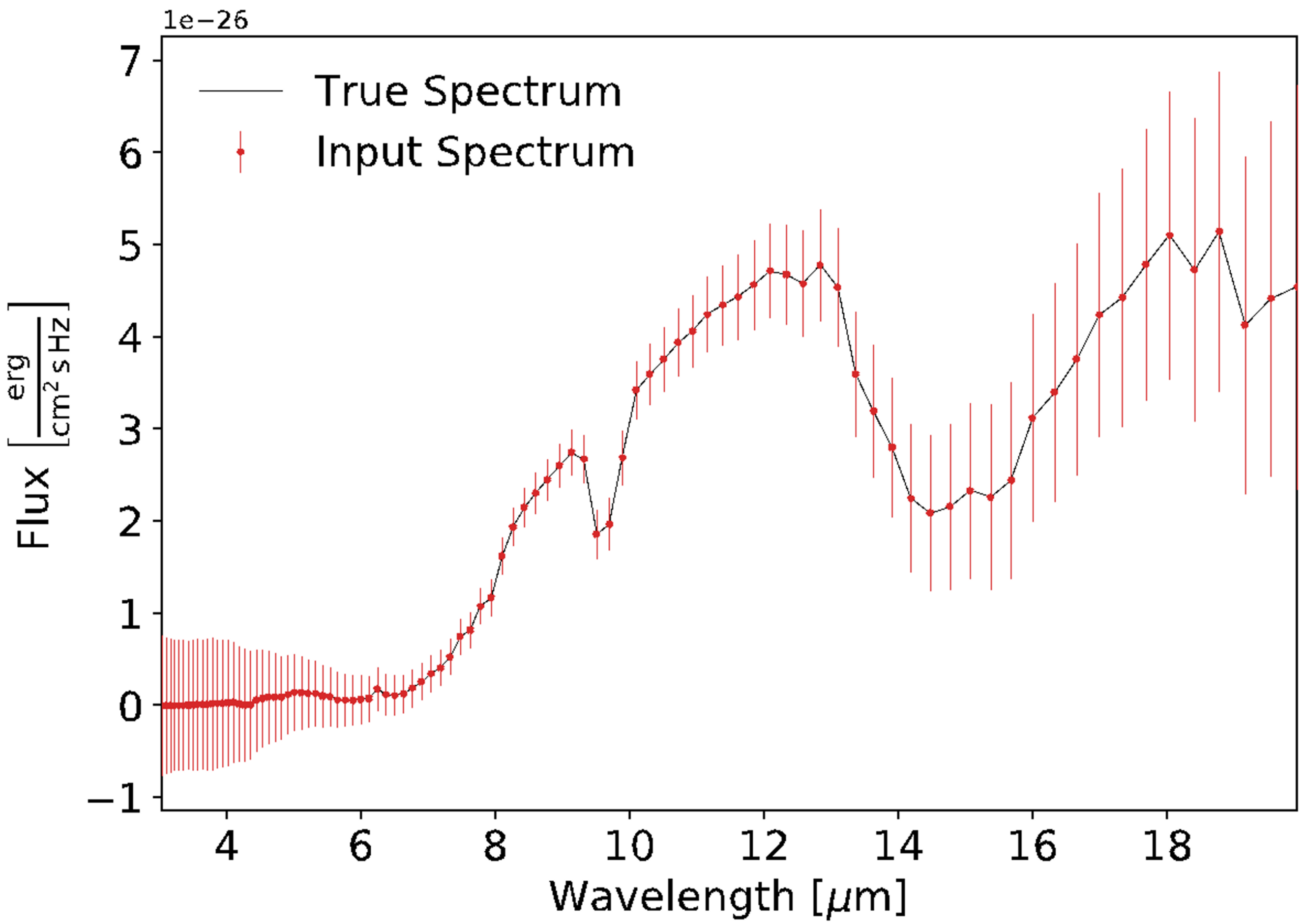
Image credit: (adapted from) NASA/JPL/Caltech; https://exoplanets.nasa.gov/exep/technology/technology-overview/ (accessed July 4, 2019)

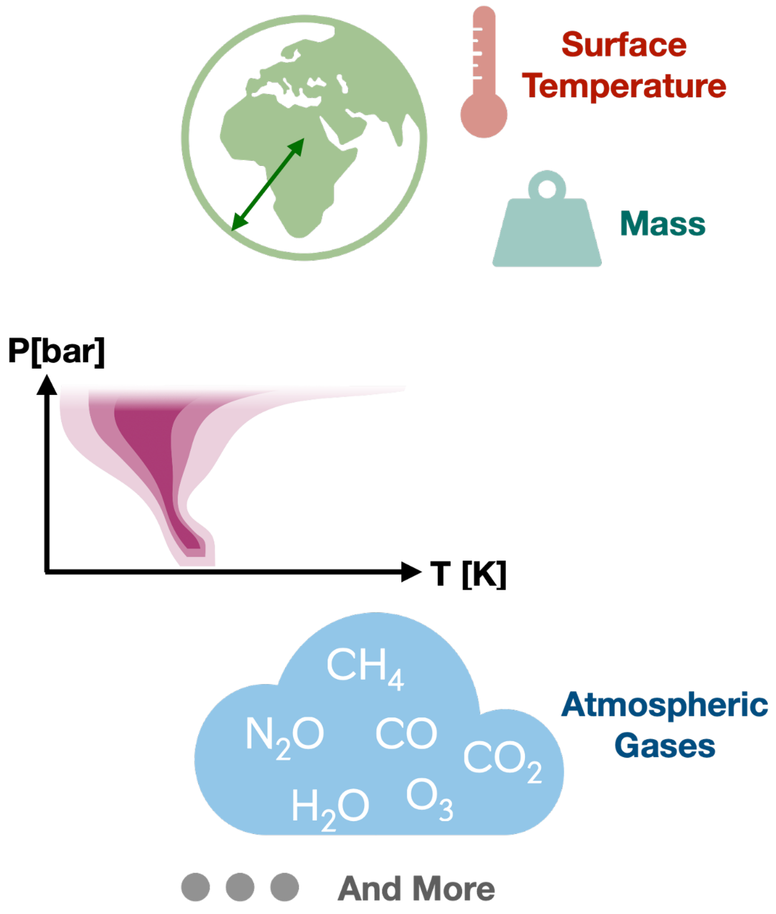
LIFE
LARGE INTERFEROMETER FOR EXOPLANETS

Atmospheric Retrievals with LIFE

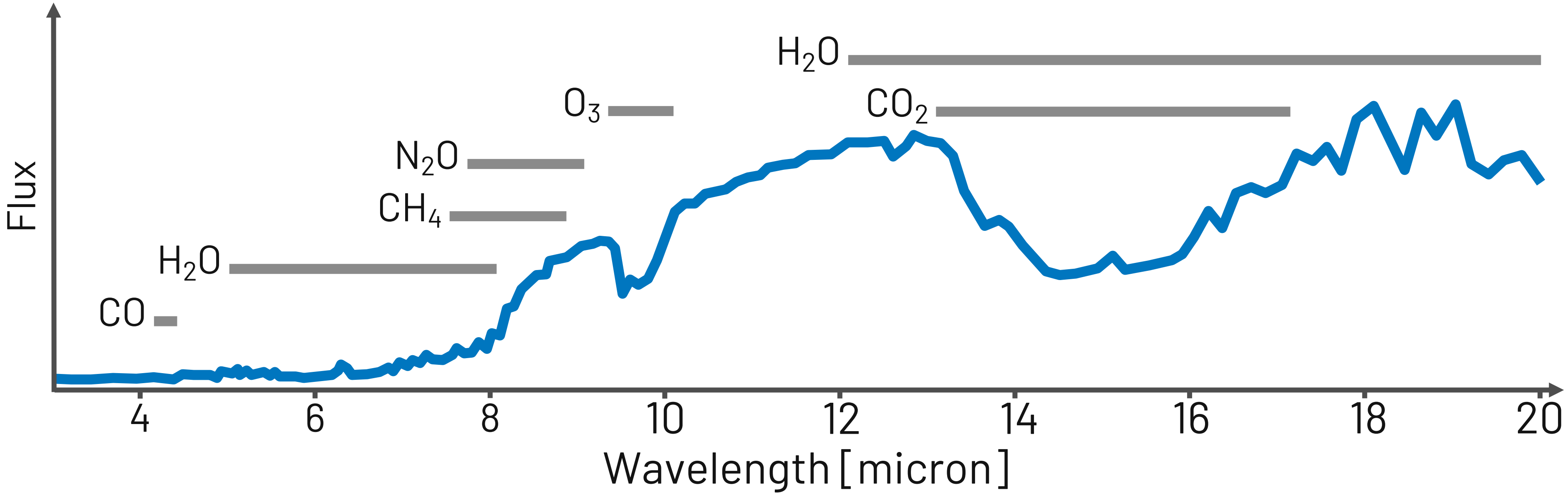
From Spectra to Characterization

The Goal of Atmospheric Retrievals





LIFE III (Konrad+2022)

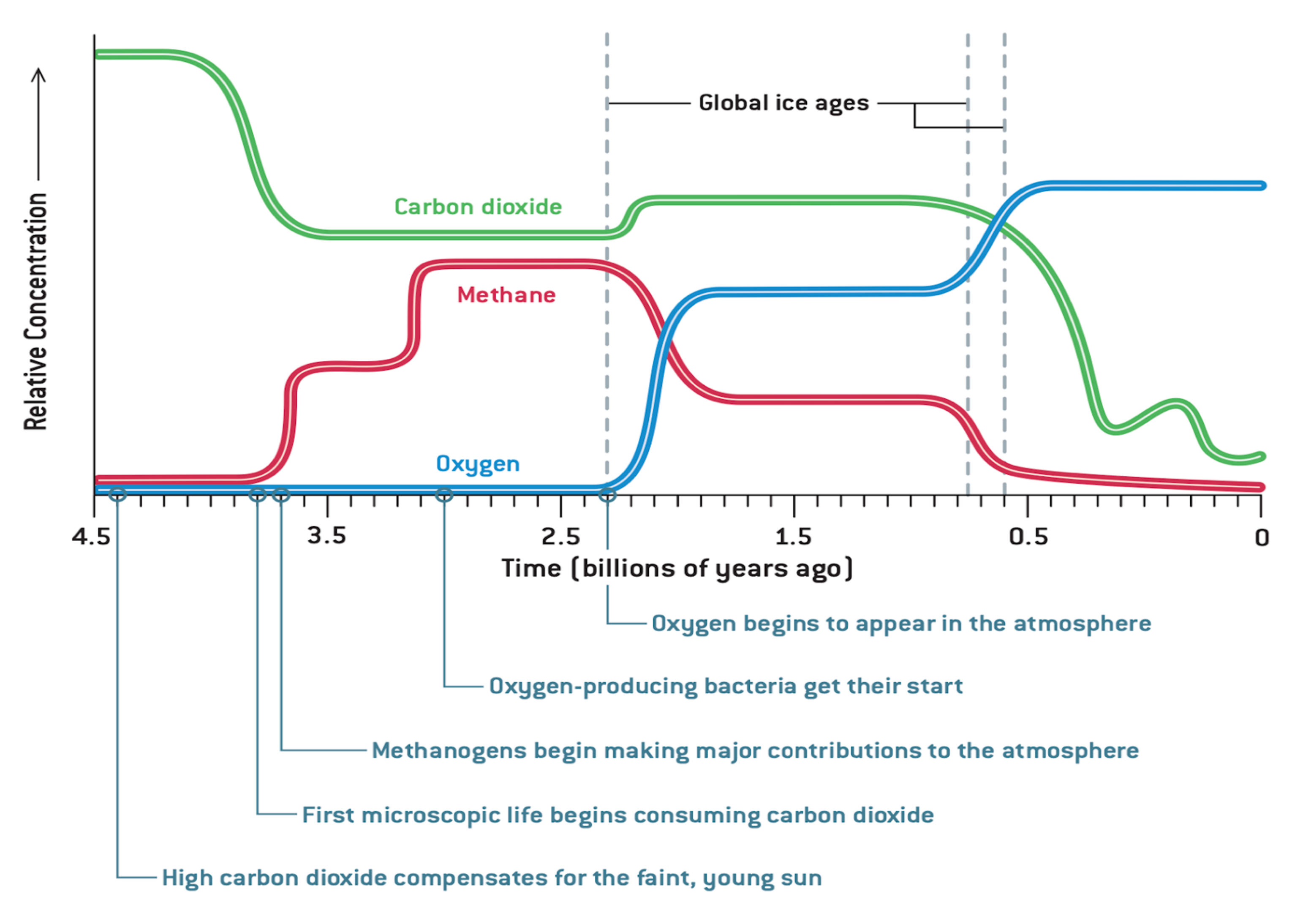


- Minimum requirements for LIFE (based on a CH_4 detection in Earth's atmosphere):
  - Primary mirror size $\geq 4 \times 2$ m
  - Wavelength range $\geq 4-18.5$ μm
  - Spectral resolution ≥ 50
  - Signal-to-noise ratio ≥ 10

See Björn Konrad's talk on Wednesday (Domain 3 splinter)!

LIFE V (Alei+subm.): The Earth in time

Evolution of the Earth’s atmosphere (James Kastings, Scientific American, June 2004)



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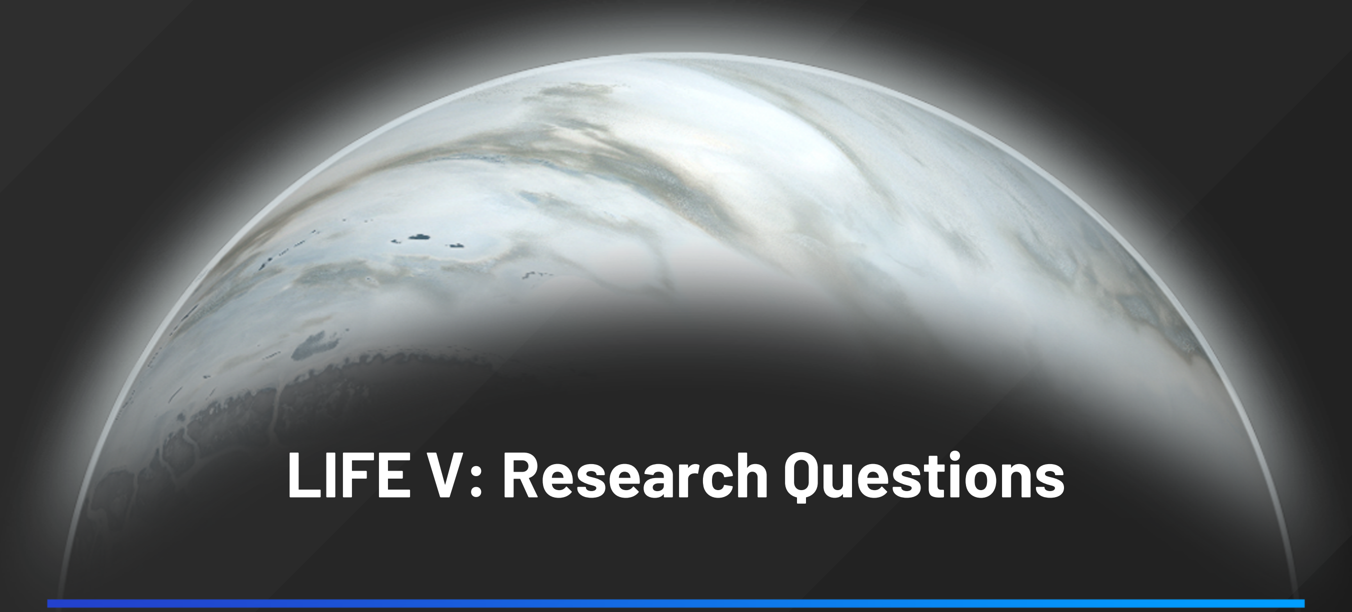

LIFE V: Research Questions

1. Can LIFE **distinguish between different epochs** of the evolution of the Earth?

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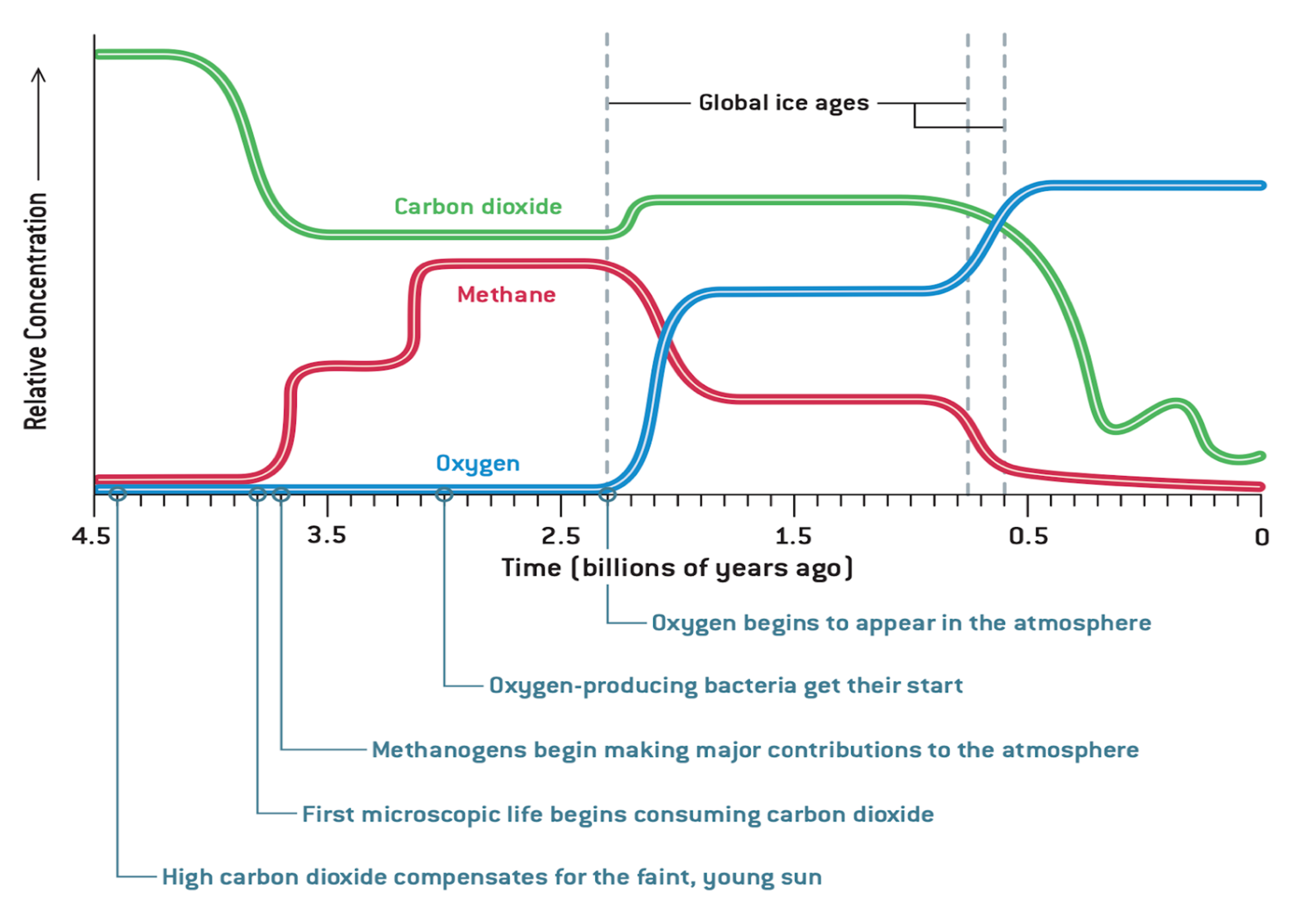
3. What is the impact of **clouds** in the retrievals?
4. Are the **minimum requirements** found in LIFE III still **sufficient**?

LIFE V: Input models

Evolution of the Earth's atmosphere (James Kastings, Scientific American, June 2004)



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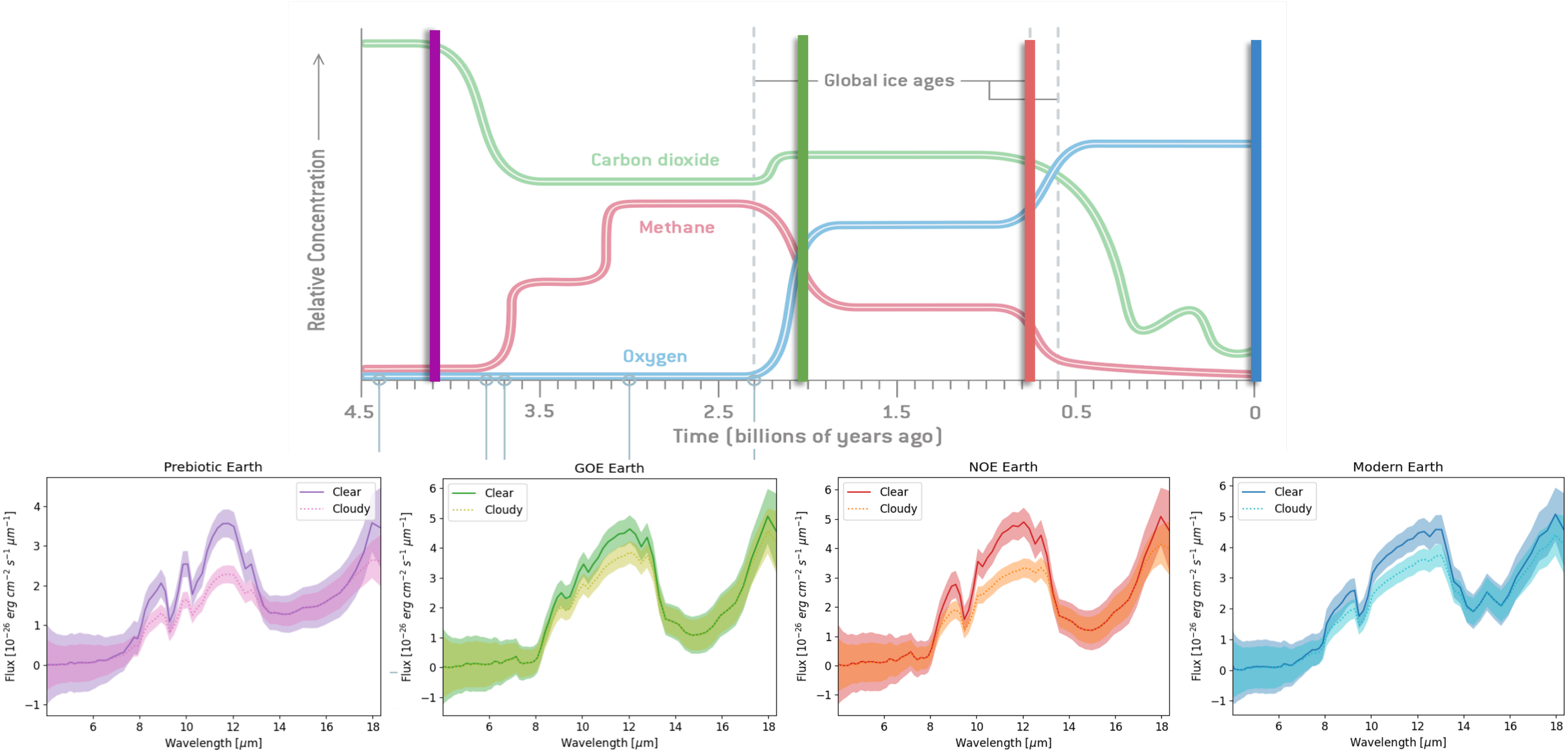
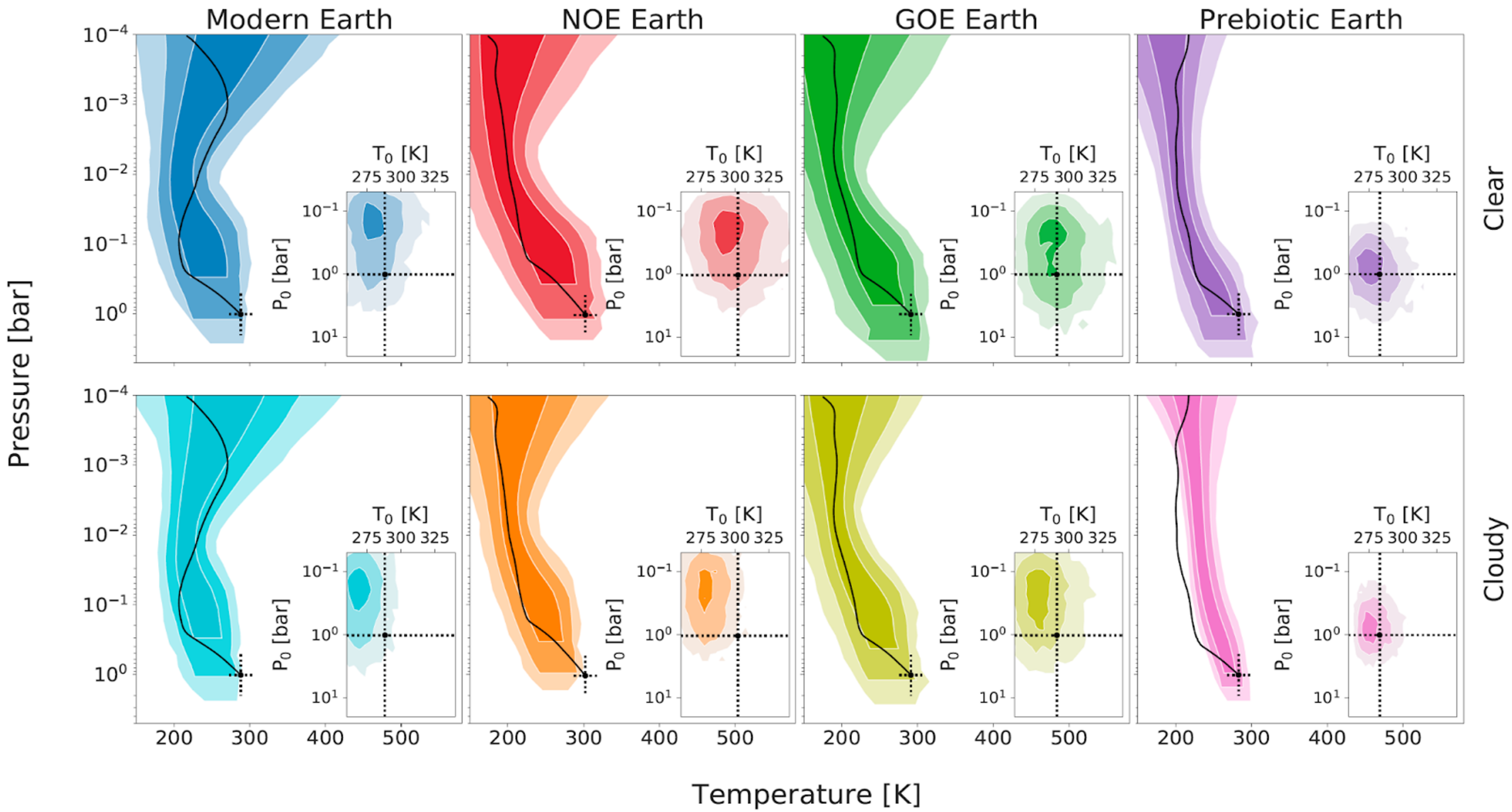


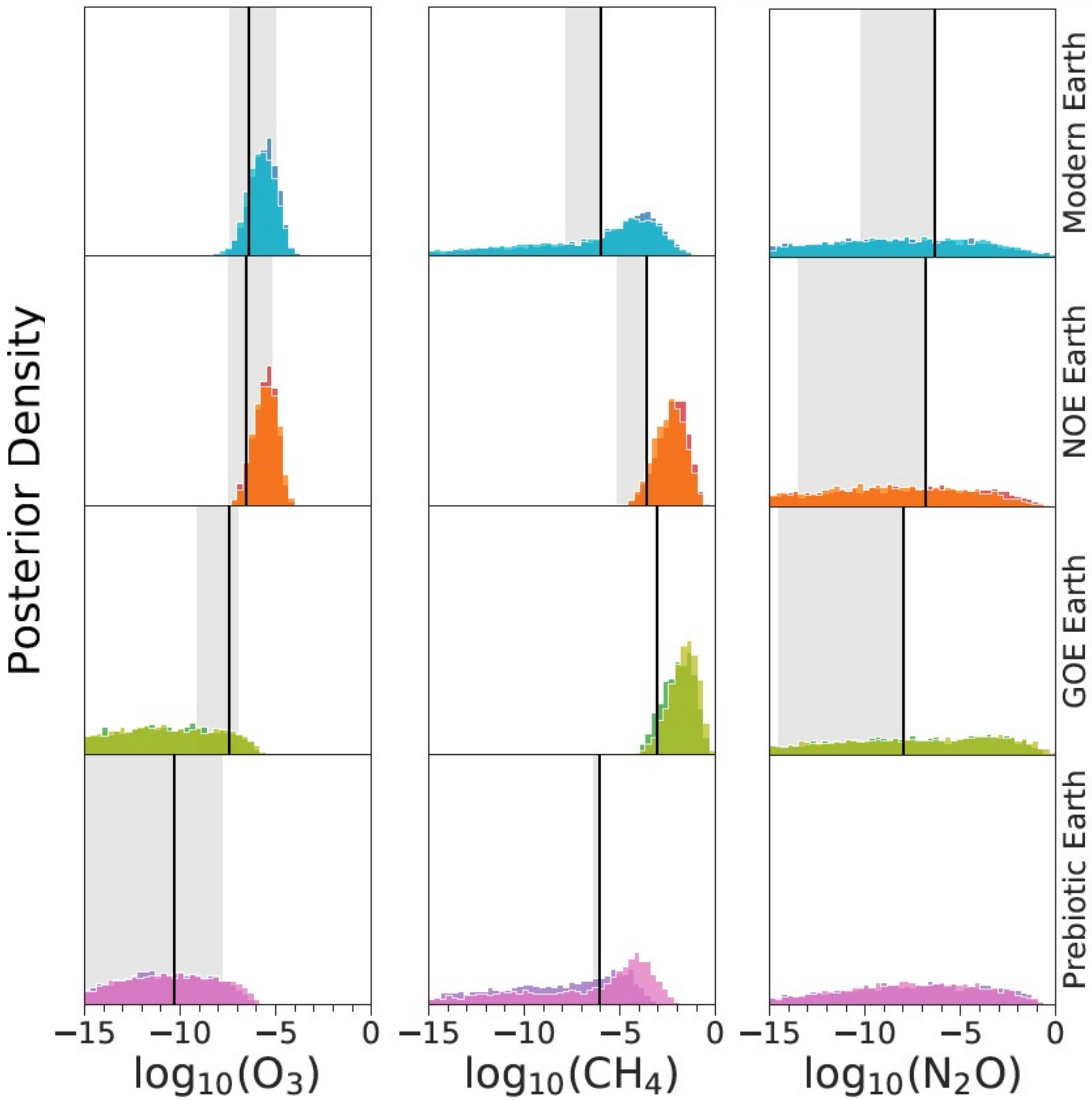
Thermal structure

- Good estimates of ground temperature ($\pm$ 20 K).
- Larger uncertainties on pressure (degenerate with chemical composition).
- **Cloudy models**: We neglect clouds in retrievals, so we retrieve cooler surface temperatures.



Chemical abundances

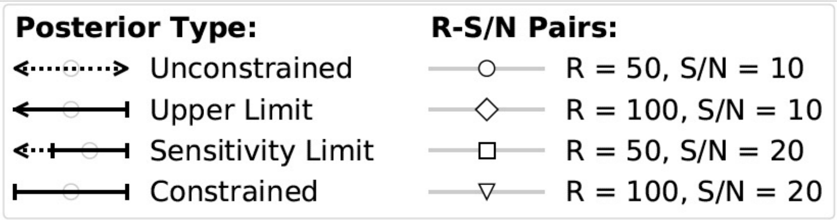
- O_3 and CH_4 detected at higher abundances, upper limit at lower abundances → **promising to differentiate the various epochs.**
- **Cloudy models**: Similar performance between cloud-free and cloudy models (while neglecting clouds).
- **Sweet spot**: NOE Earth (not too much CH_4 to deplete O_2/O_3, but enough O_3 to be detected).

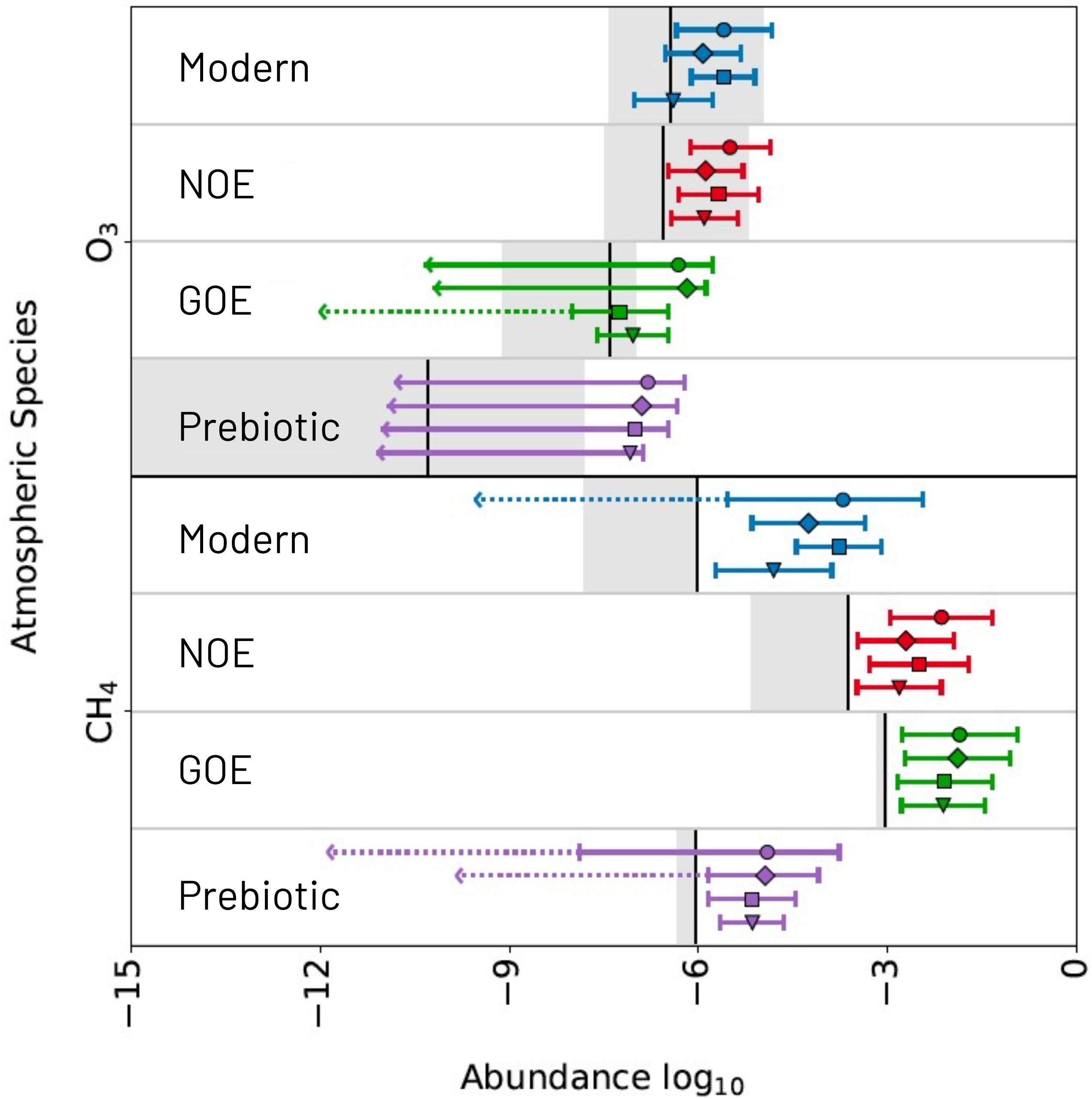


Chemical abundances

- Increasing the sensitivity of the instrument would improve the results.

- But:
  - doubling the resolution → doubling of the integration time (from ~ 50 to ~ 100 days).
  - doubling the S/N → integration times roughly four times longer (from ~ 50 to ~ 200 days).





LIFE V: Take-home message

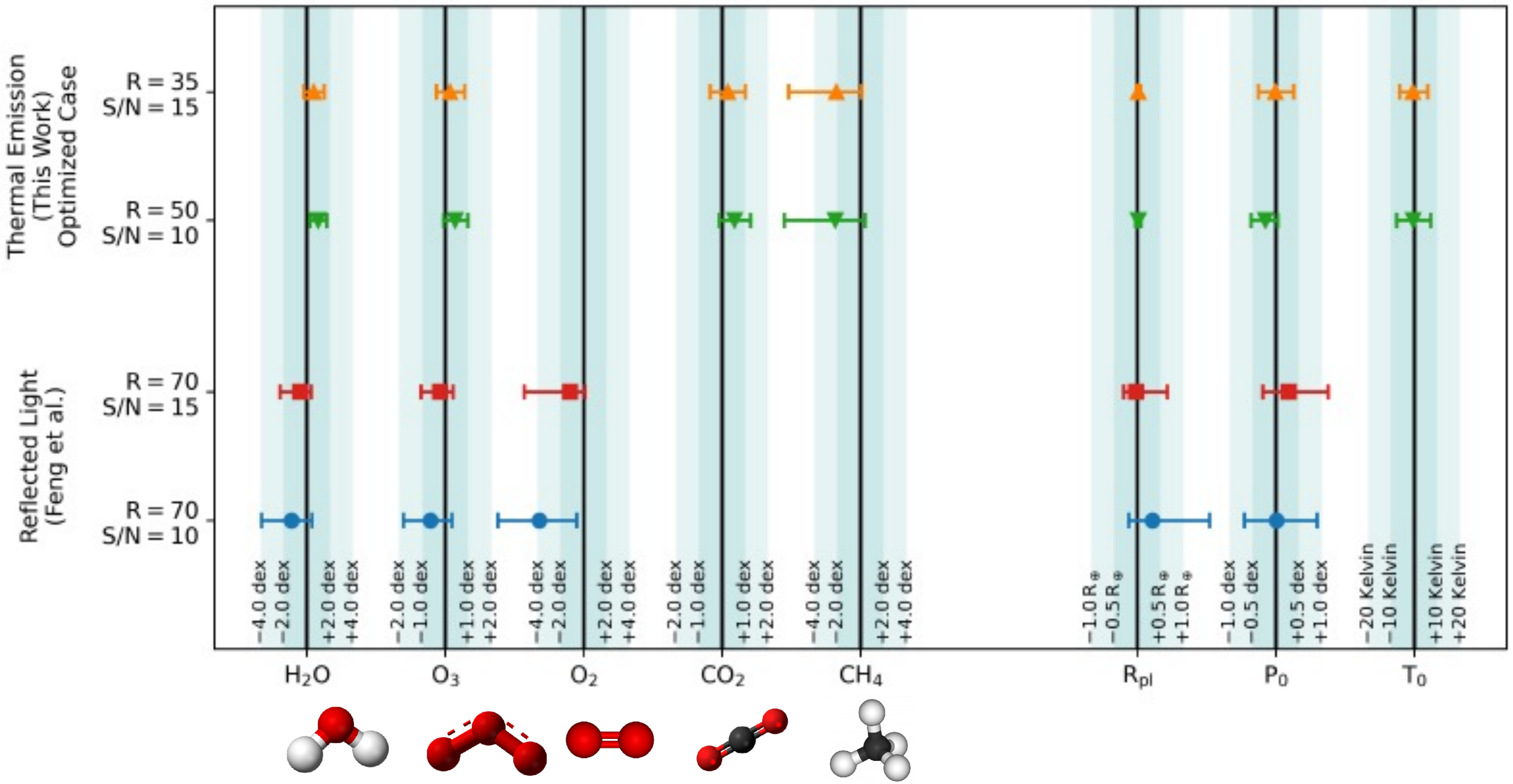
1. Can LIFE distinguish between different epochs of the evolution of the Earth? LIFE can characterize prebiotic and biotic worlds. We can constrain the surface temperatures with an uncertainty of around 20 K.

2. What are the most promising "tracers" to detect life? If LIFE were to observe the Earth at various stages of its evolution, it would detect strong indicators of life starting from around 0.8 Ga (Earth after the Neoproterozoic Oxygenation Event). LIFE would tentatively detect potential biological activity up to 2.0 Ga (Earth after the Great Oxygenation Event).

3. What is the impact of clouds in the retrievals? Running cloud-free retrievals on cloudy spectra would still yield accurate estimates for the atmospheric composition. However, it would bias the retrieval of the atmospheric thermal structure.

4. Are the minimum requirements found in LIFE III still sufficient? Yes. Improving the S/N would allow for a clearer detection of O_3 and CH_4 (up to an abundance of ~10^{-7} in mass fraction).

What comes next: VIS+IR retrievals



Konrad+(LIFE III)

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Save the date!
All-hands meeting:
June 8, 2022

Latest News

- **New LIFE "design":** over the next weeks we will transition to a new design, including a complete overhaul of our website, poster and slide templates etc.
- **LIFE at conferences** in the next few weeks (e.g. Exoplanets IV, AbSciCon, and SPIE)
- **Adjustments of LIFE team structure:** if you are interested to take more responsibilities in the LIFE team, e.g. as team or working group lead please contact us
- **LIFE papers:** papers 1-3, from the LIFE paper series are now accepted, paper 5,6 on the arXiv

Check our webpage: **www.life-space-mission.com**
Sign up for newsletter: **life@phys.ethz.ch**

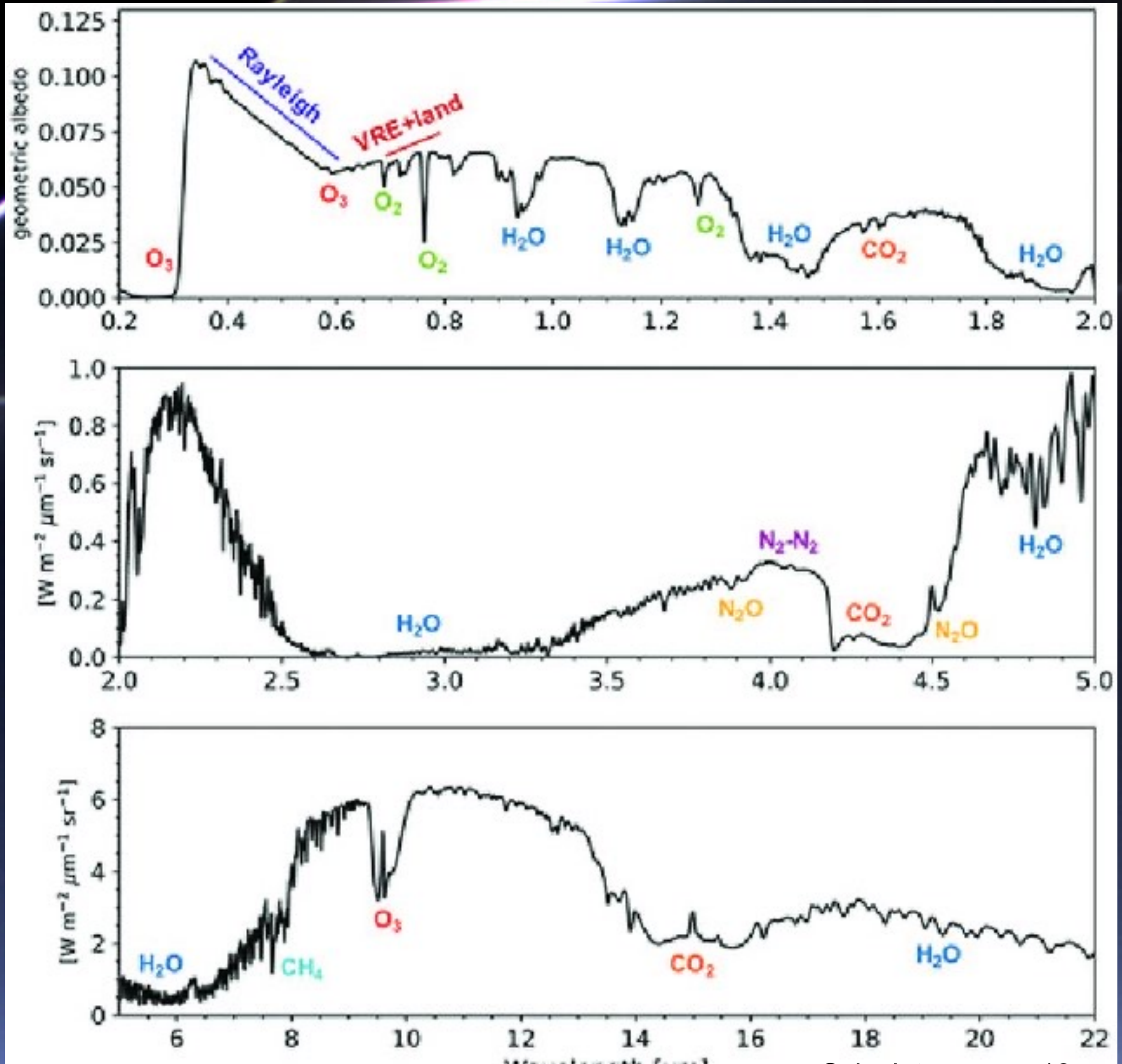
LIFE papers

Backup slides

LUVOIR

HabEx

LIFE Large Interferometer For Exoplanets



Schwietermann+18

Visible

near-infrared

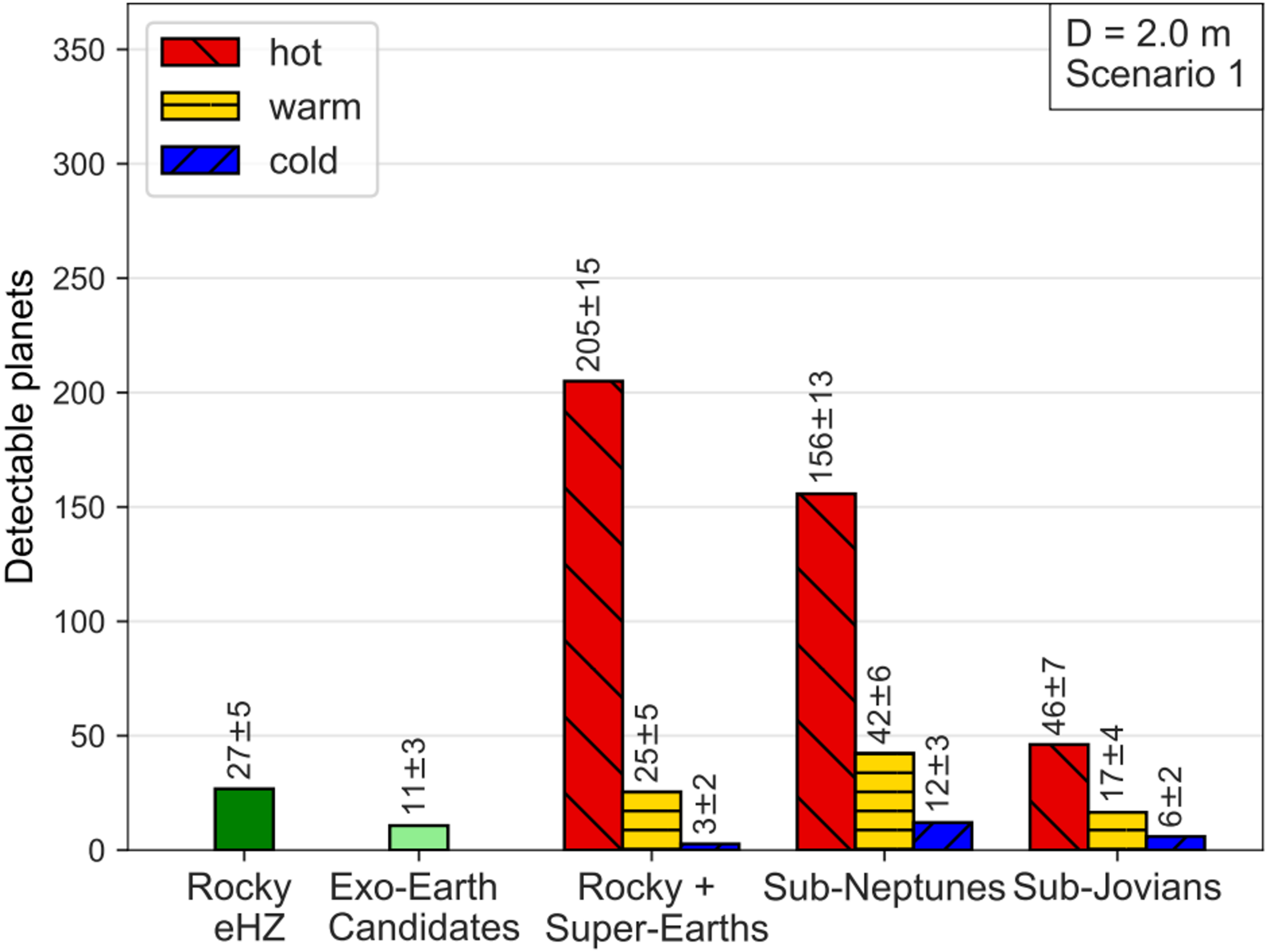
mid-infrared

Reflected

Emitted

Detection Yield

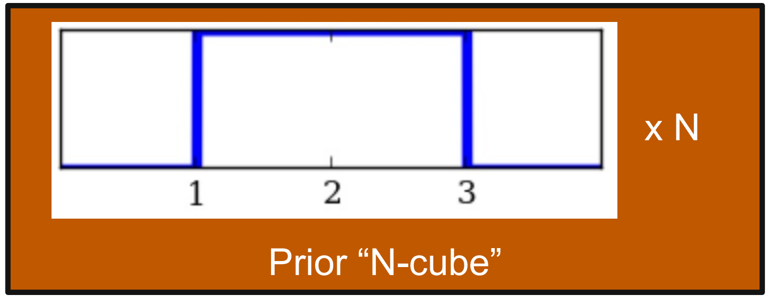
- Hundreds of planets
- Dozens of temperate rocky ones
- Most of them only accessible with LIFE

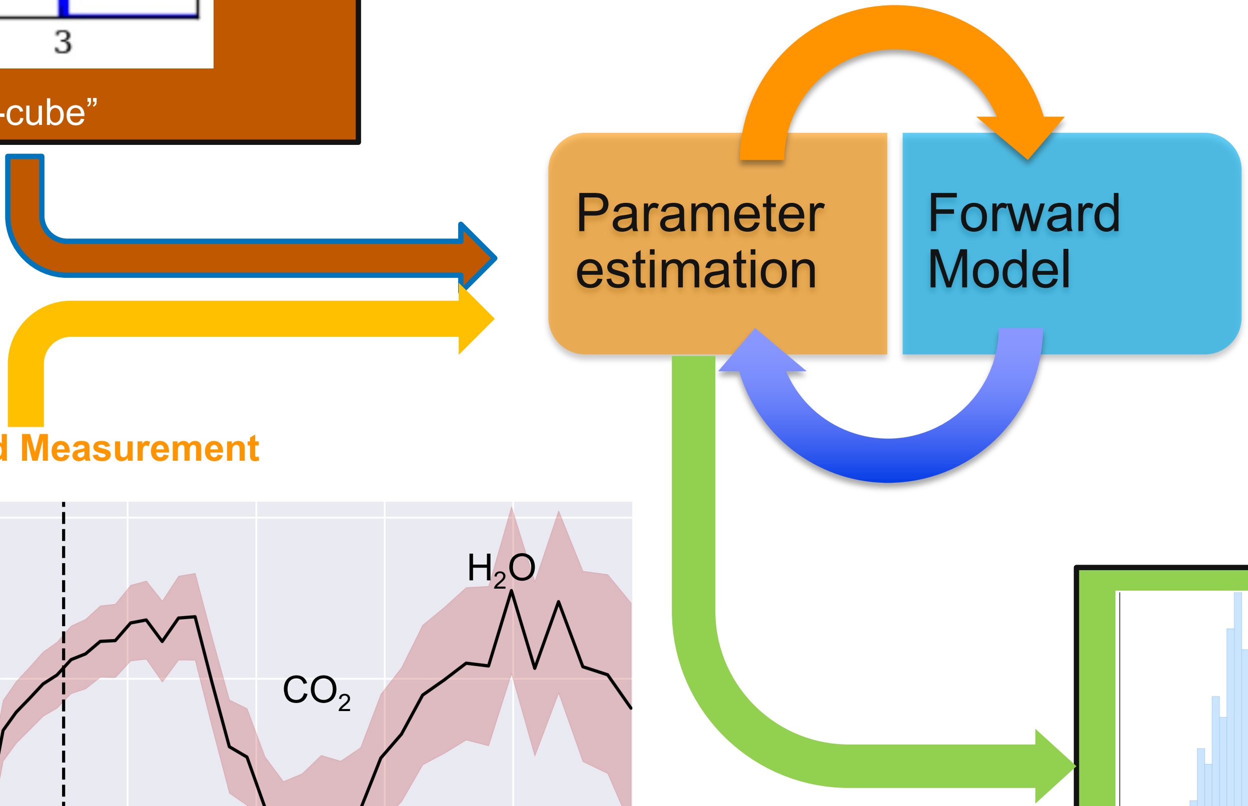


Bayesian Retrieval

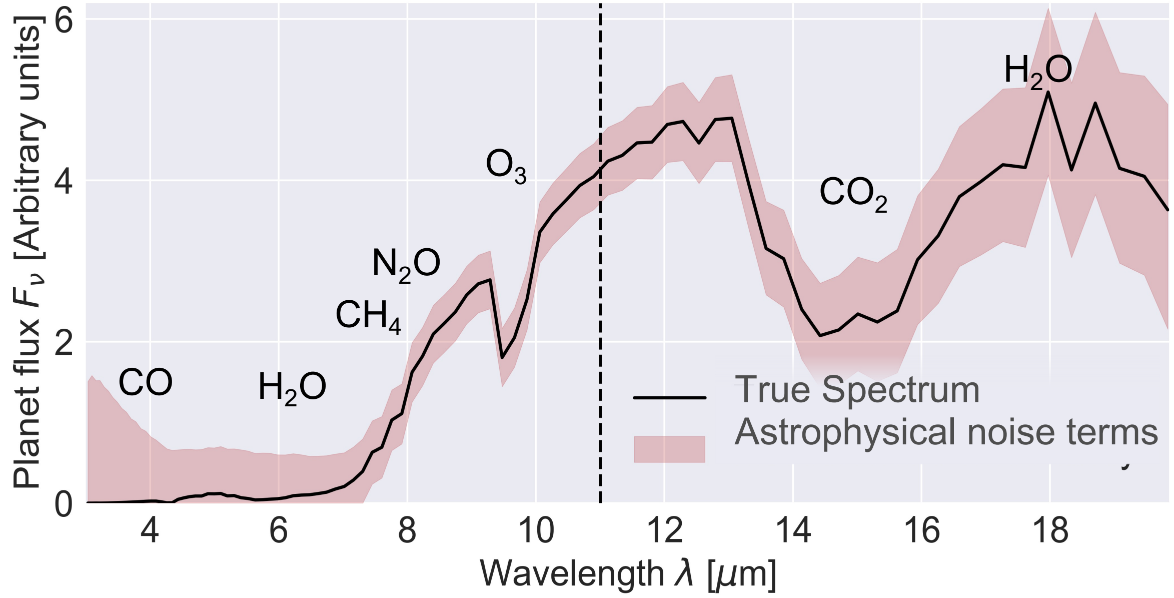
N = # Parameters

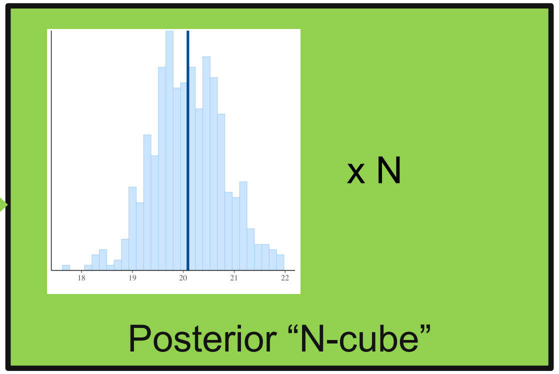
- Mass
- Radius
- p-T structure
- Chemical composition
- (clouds)
- (scattering)





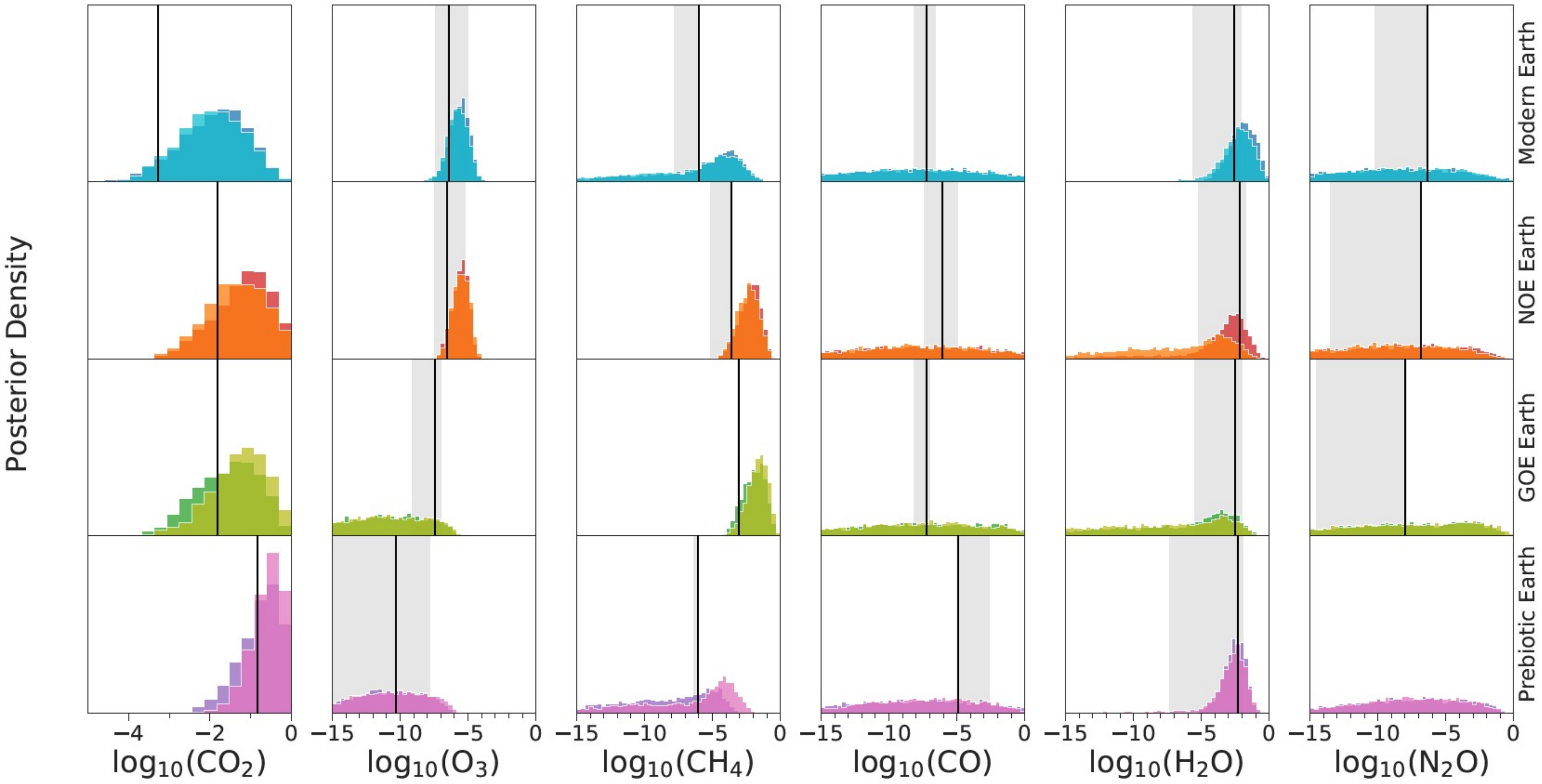
***LIFE* Simulated Measurement**





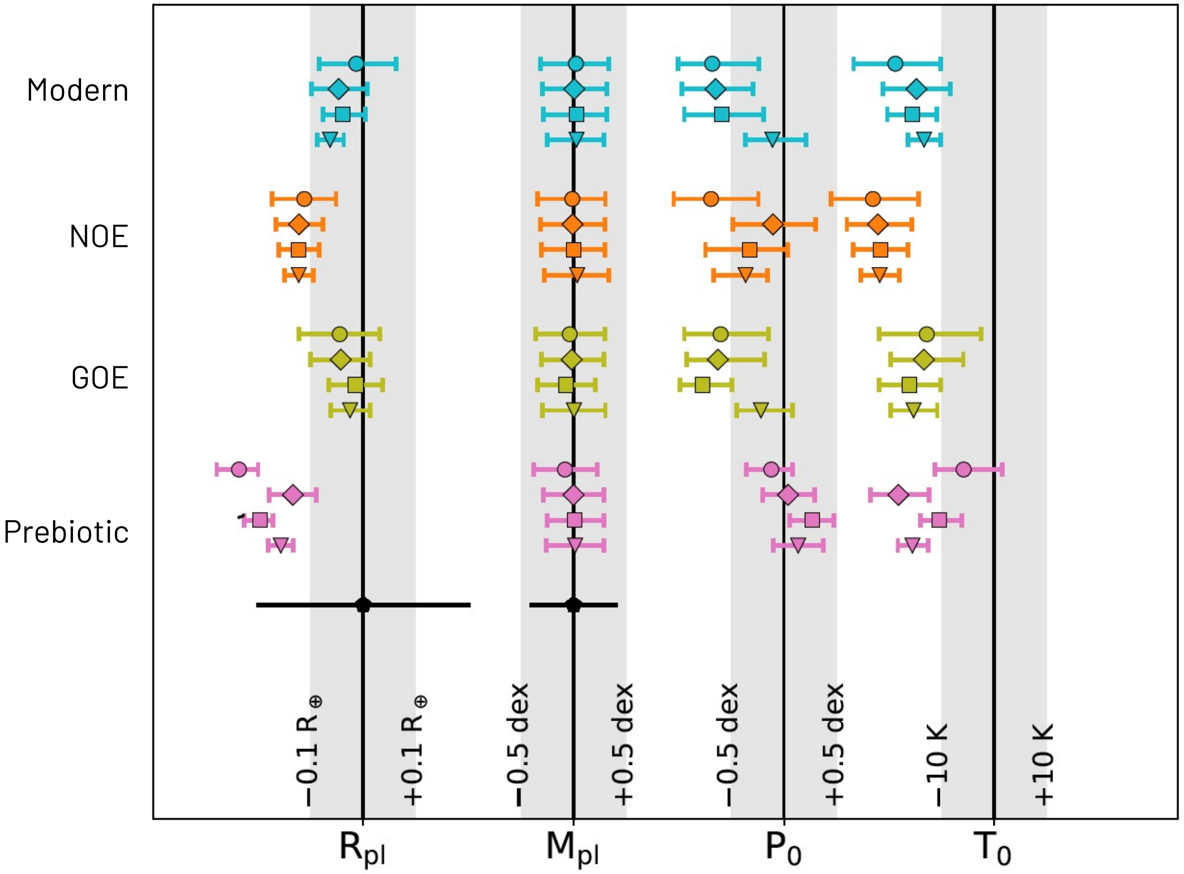
Chemical abundances

- O_3 and CH_4 detected at higher abundances, upper limit at lower abundances
- Not sensitive to CO and N_2O (and N_2/O_2)

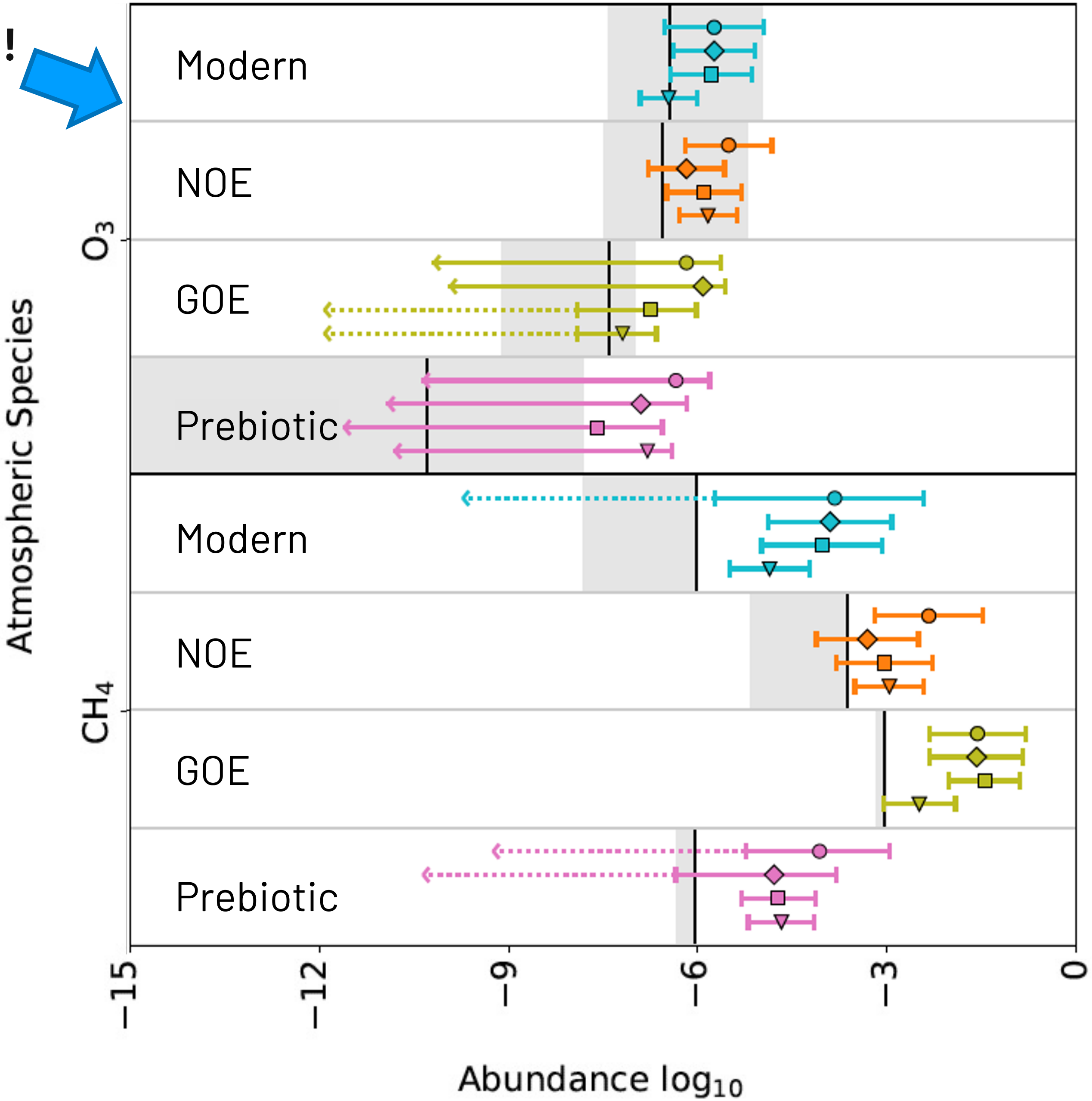


Clouds

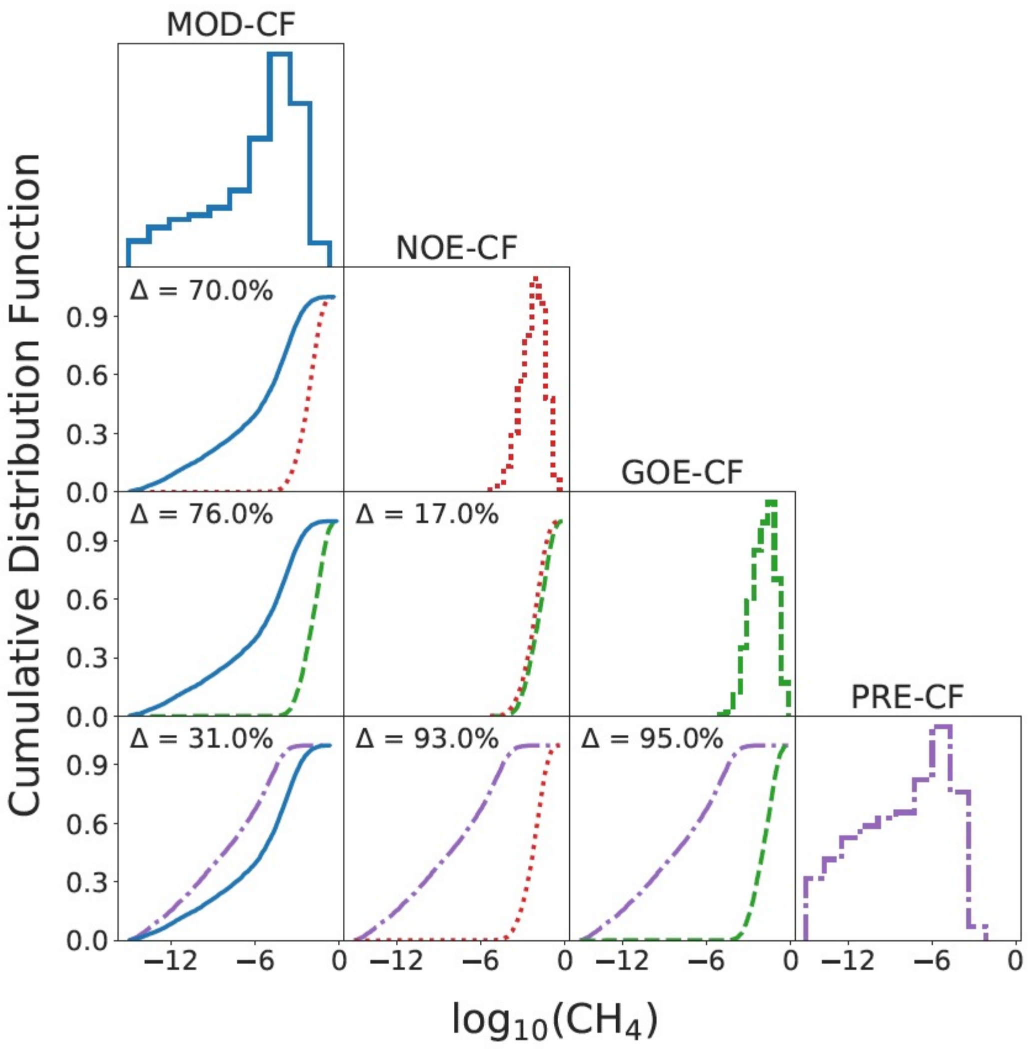
Not great



Not bad!



Differentiating the epochs



Given a model parameter M with prior range $X = [X_{\min}, X_{\max}]$, we calculate the cumulative distribution $G^M(x)$ for $x \in X$ of the retrieved posterior $P(x)$ as follows:

$$G^M(x) = \int_{X_{\min}}^{x} P(x')\,dx' \cdot \left(\int_{X_{\min}}^{X_{\max}} P(x')\,dx'\right)^{-1}. \quad (1)$$

We then compare the cumulative distribution functions $G_a^M(x)$ and $G_b^M(x)$ of two different epochs a and b, by considering the maximum difference $\Delta := \Delta_{a-b}^M \in [0,1]$ between them:

$$\Delta = \max |G_a^M(x) - G_b^M(x)|. \quad (2)$$

Thus, small values of Δ indicate that the compared posterior distributions only show small differences relative to each other. In this case it is hard to differentiate between the retrieved posteriors. On the other hand, larger values of Δ indicate that the differences between the two posteriors are likely to correspond to different underlying true values of the considered parameter.

Differentiating the epochs