PLATO - ESP 2025
Planets throughout the Habitable Zone

Università degli Studi di Padova

Atmospheric Evolution and Potential Habitability of Sub-Neptunes: A Comparative Study in the PLATO Era

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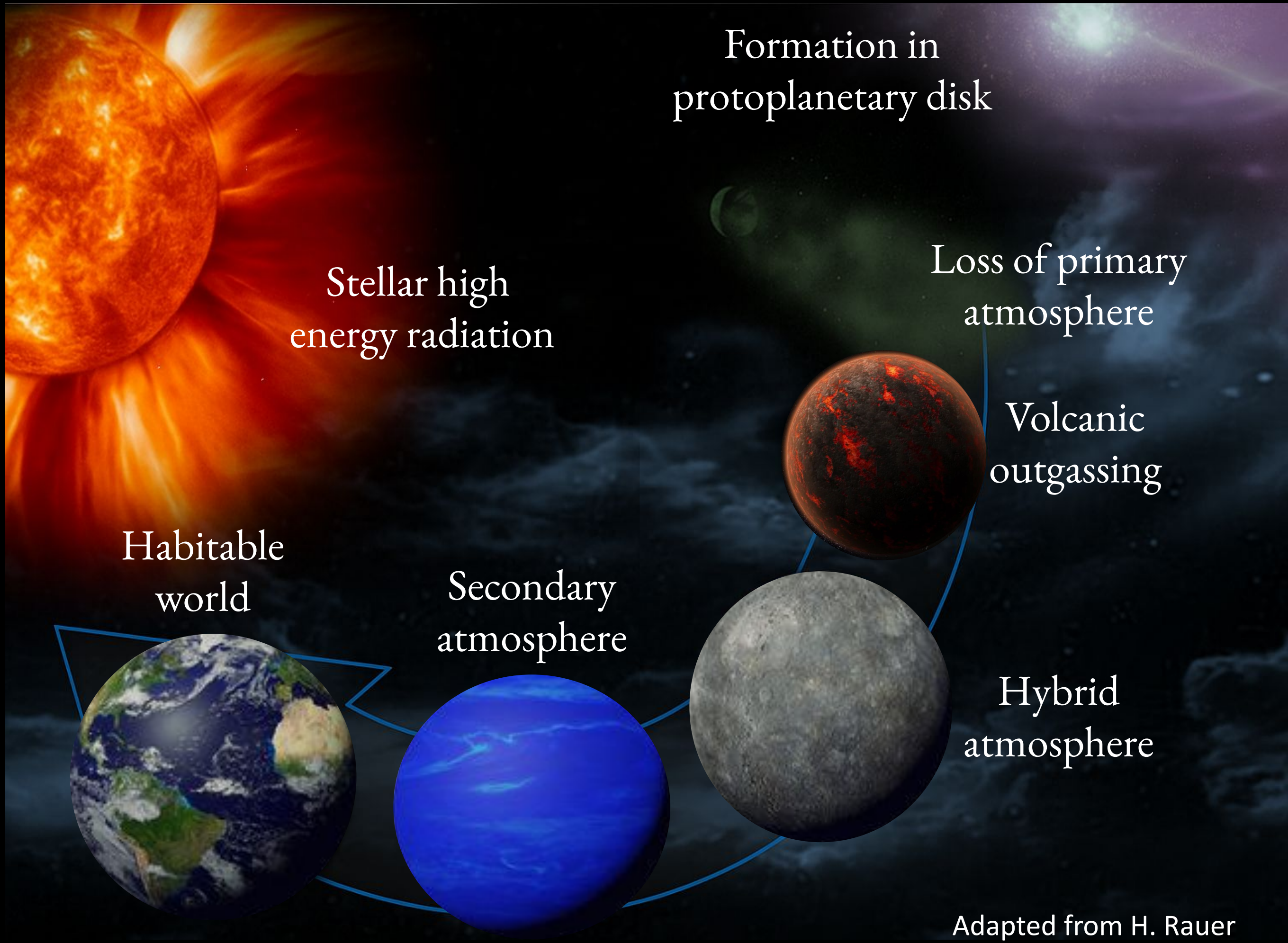
Why to Study Small Exoplanets

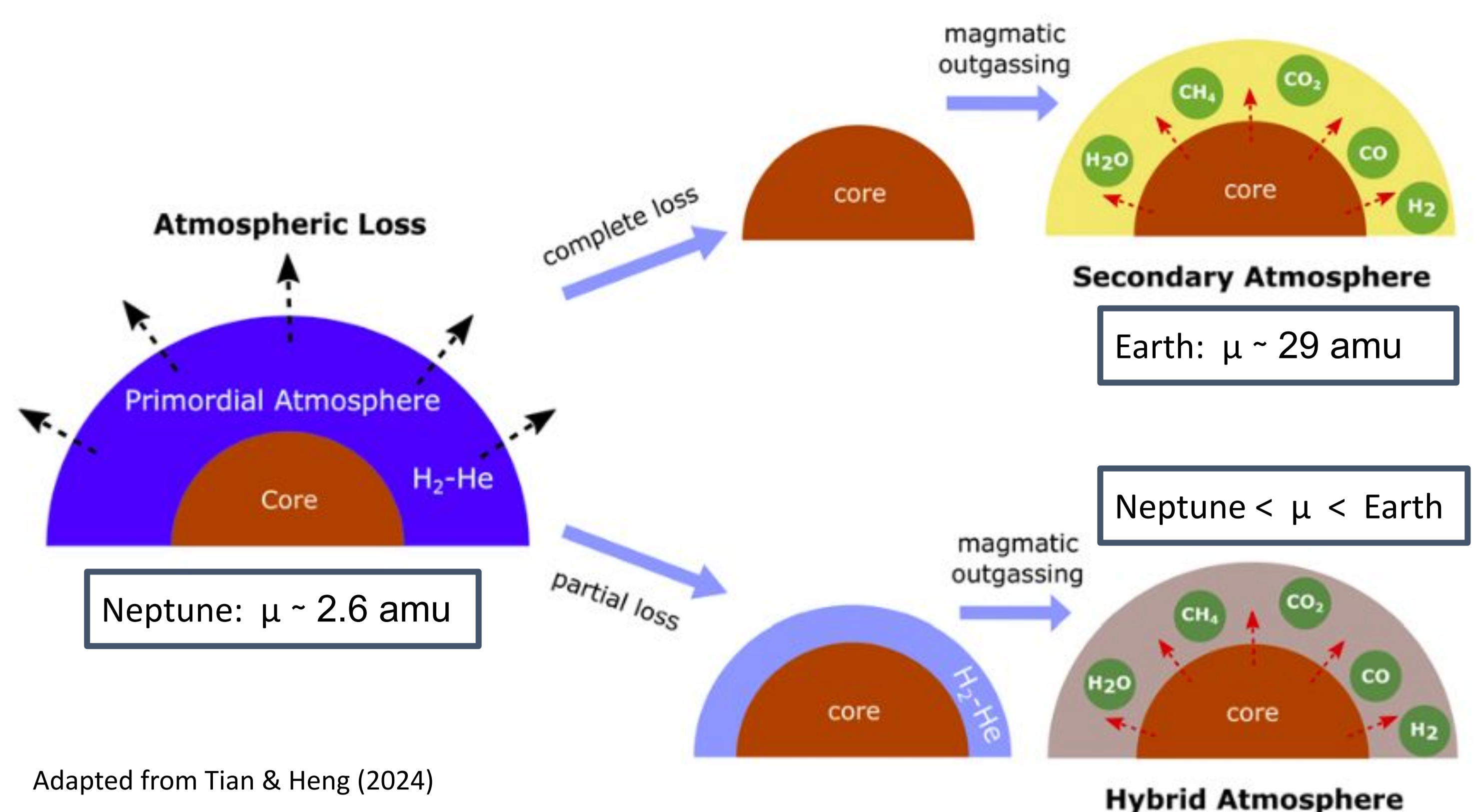
1. **Formation**
2. **Atmospheric Evolution**
3. **Habitability**



The Atmosphere of Small Exoplanets

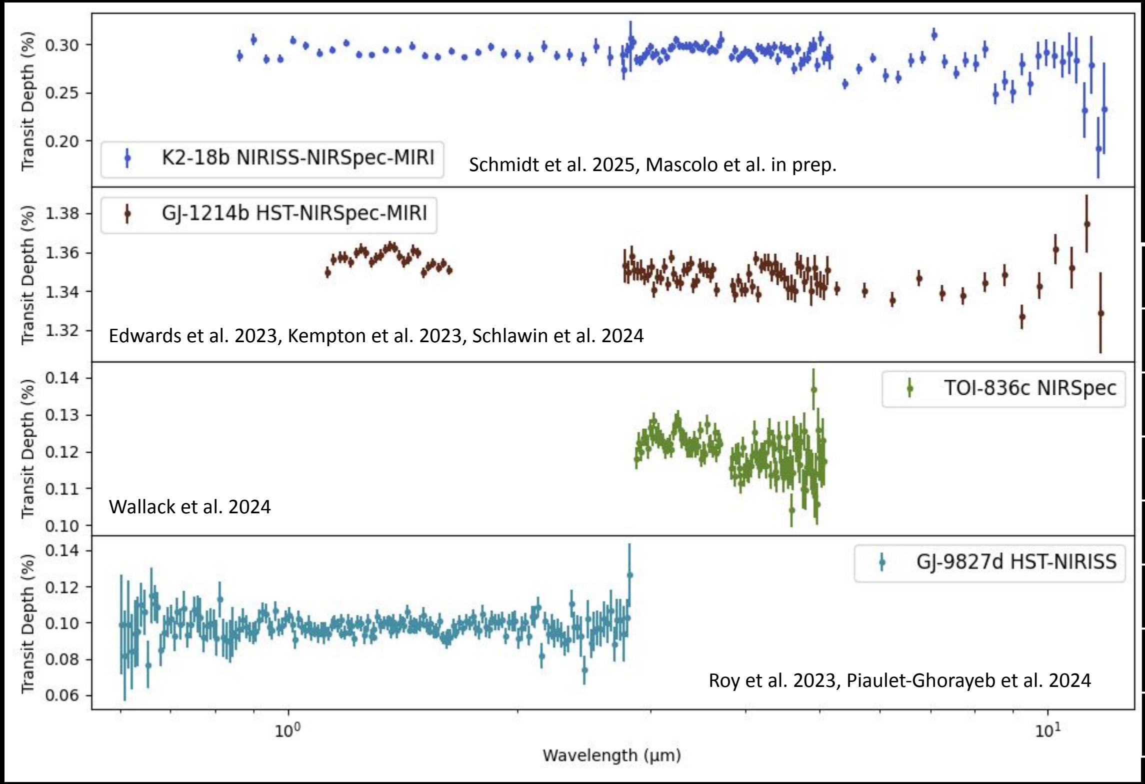
To distinguish between atmospheric type:

- The atmospheric evolution over time
- The chemical composition



Adapted from Tian & Heng (2024)

Population Study of Sub-Neptunes



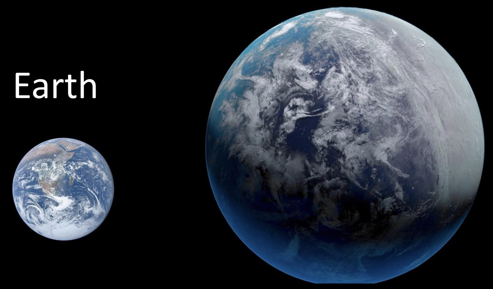
Project Goal:

Build a population study by analyzing four sub-Neptunes in pairs, then jointly, to identify common characteristics and evolutionary patterns.

Planet	K2-18 b	GJ 1214 b	TOI-836c	GJ 9827 d
M_p (M_e)	8.63 ± 1.35	8.41 ± 0.36	9.60 ± 2.70	3.02 ± 0.58
R_p (R_e)	2.61 ± 0.09	2.73 ± 0.03	2.59 ± 0.09	1.98 ± 0.11
T_p (K)	255 ± 4	567 ± 7	665 ± 27	675 ± 14
Type Star	M2.8 V	M4 V	K V	K7 V
M_s ($M_\odot$)	0.47 ± 0.04	0.18 ± 0.01	0.68 ± 0.04	0.62 ± 0.04
R_s ($R_\odot$)	0.461 ± 0.004	0.21 ± 0.01	0.66 ± 0.01	0.58 ± 0.03
Age (Gyr)	2.4 ± 0.6	<3	5 ± 6	5 ± 4

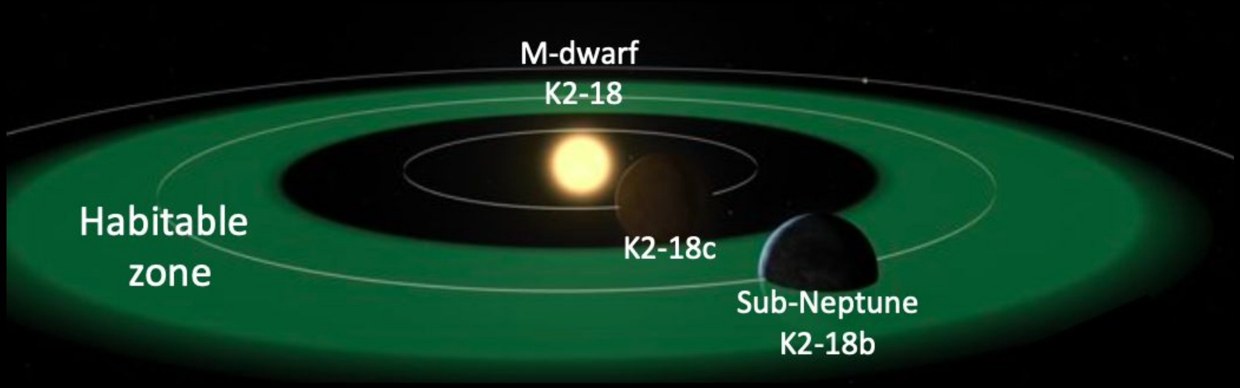
NASA Exoplanets Archive

Focus on Planet K2-18b



Discovered in 2015, K2 mission

K2-18b orbits an **M-dwarf star** with only 2.53% of the Sun’s luminosity, yet it receives a stellar flux of **1368 W/m^2**, very close to Earth’s ~1361 W/m^2



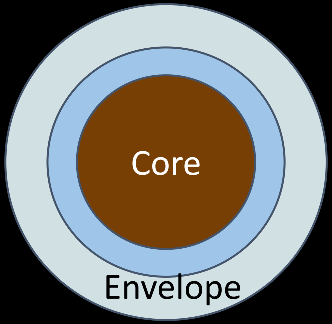
M_p (M_e)	8.63 ± 1.35
R_p (R_e)	2.61 ± 0.09
T_p (K)	255 ± 4
P (days)	32.9396 ± 10^{-4}
Type Star	M2.8 V
M_s ($M_\odot$)	0.47 ± 0.04
R_s ($R_\odot$)	0.461 ± 0.004
Age (Gyr)	2.4 ± 0.6

Atmospheric Evolution of K2-18b

We modeled the structure and evolution of K2-18b's atmosphere over time, accounting for:

- **Gravitational contraction**
- **Stellar XUV-driven photoevaporation**

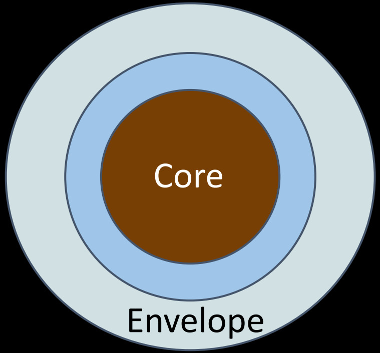
Current age - 2.4 Gyr



Earth-like core: 67% rock, 33% ice
~8.4 $M_\oplus$, ~1.7 $R_\oplus$

Envelope: 2.25% mass
~0.19 $M_\oplus$, ~0.8 $R_\oplus$

Early age - 10 Myr



Envelope: ~2× larger but only 10% more massive

Gravitational contraction, not loss from photoevaporation

Photoevaporation had little effect on atmospheric mass → Composition is likely **primordial**

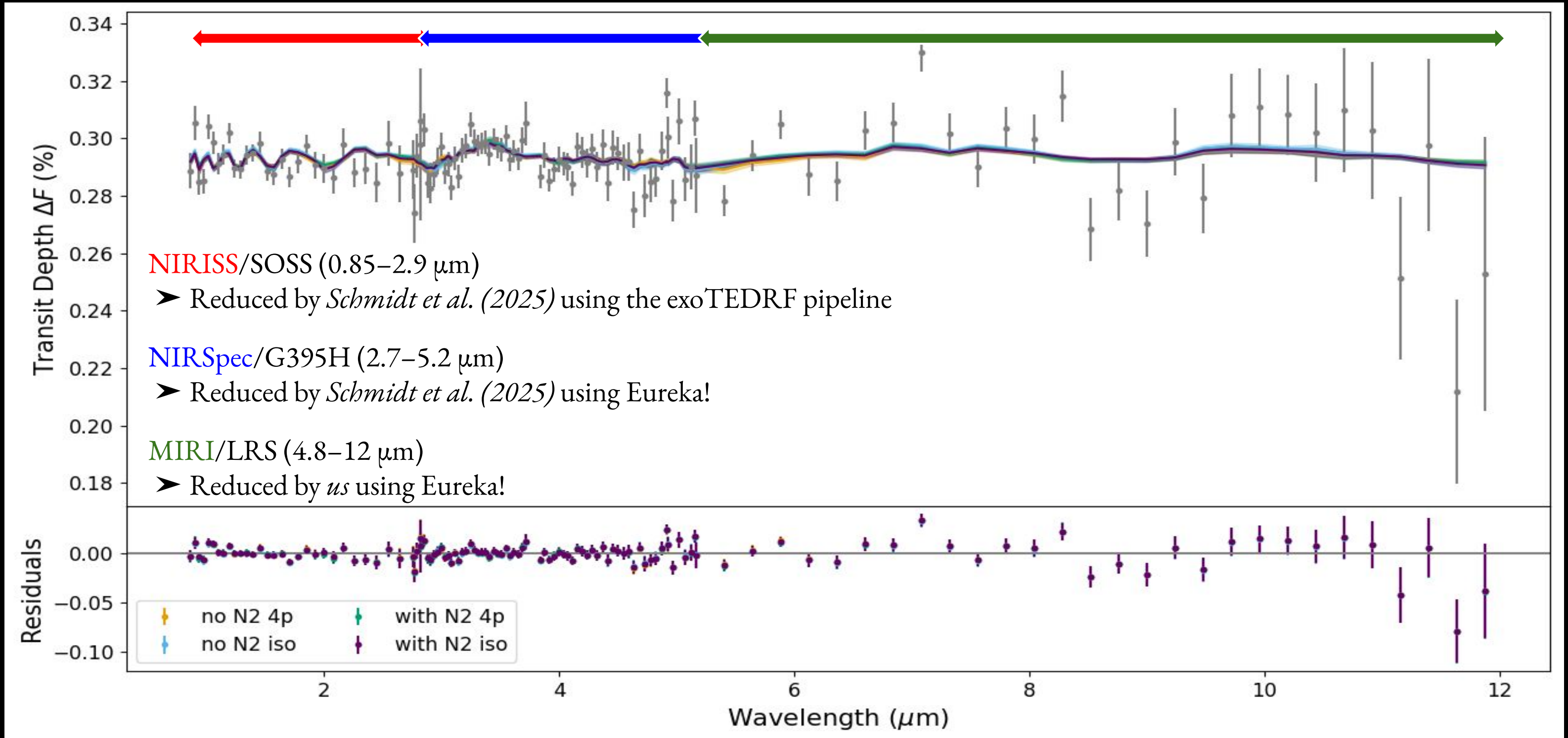
What Molecules in K2-18b ?

Atmospheric Analysis of K2-18b

Retrieval framework: TauREx3 (Al-Refaie+2021,2022)

Chemical model: Free Profile
Active molecules: H_2O, CH_4, NH_3, CO_2, CO, HCN
Active biomolecules: DMS, DMDS
Inert molecules: H_2, He, N_2

T-P profile: Isothermal vs. 4-point profile

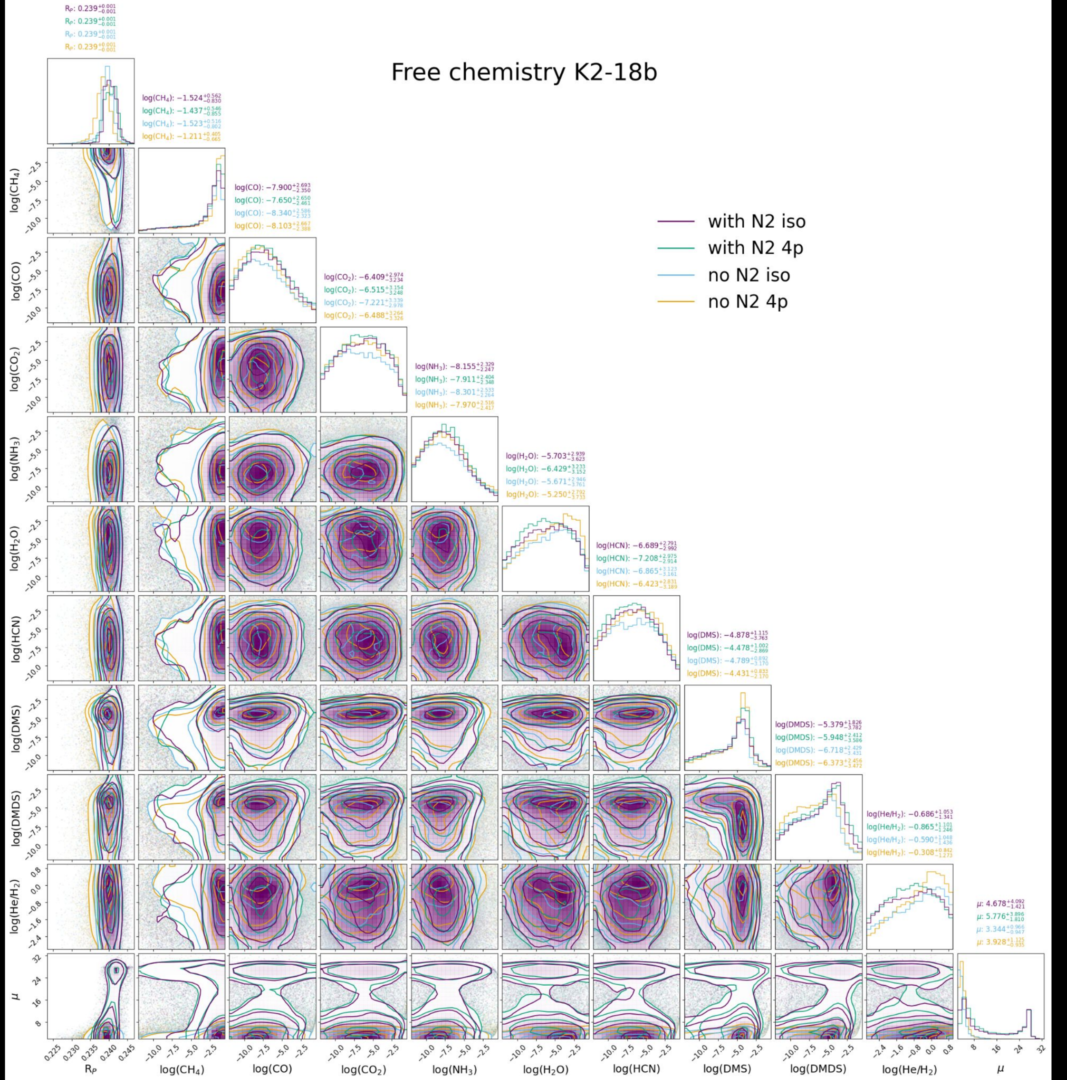


Posterior distributions of K2-18b

4 models: change T-P profile and add N_2

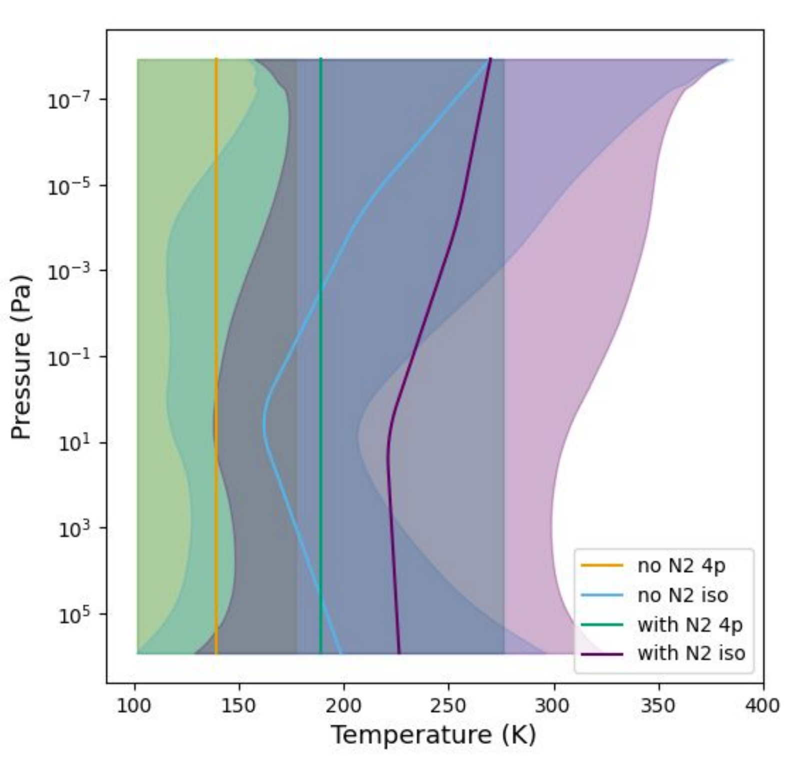
Fitted parameters with uniform priors:

- Planetary radius
- T-P parameters
- Active molecules
- Ratio of inactive molecules



Temperature-Pressure Profile

Compatible to isothermal within 1σ



Statistical Comparison

Atmospheric Detectability Index (ADI),

a positively defined Bayes factor calibrated on the Jeffreys' scale

$$ADI = \begin{cases} \log(BF_1) - \log(BF_2), & \text{if} \quad \log(BF_1) > \log(BF_2) \\ 0, & \text{otherwise} \end{cases}$$

- ADI > 3 → Significant atmospheric detection at 3σ
- ADI < 3 → Unable to favour a model

no N2 iso - with N2 iso:	1.27
no N2 4p - no N2 iso:	0.24
no N2 iso - with N2 4p:	1.59
no N2 4p - with N2 iso:	1.51
with N2 iso - with N2 4p:	0.31
no N2 4p - with N2 4p:	1.83

Occam's Razor → no N2 iso

Conclusions and Future Directions

Planet K2-18b

Atmospheric evolutionary model

Primary atmosphere

+

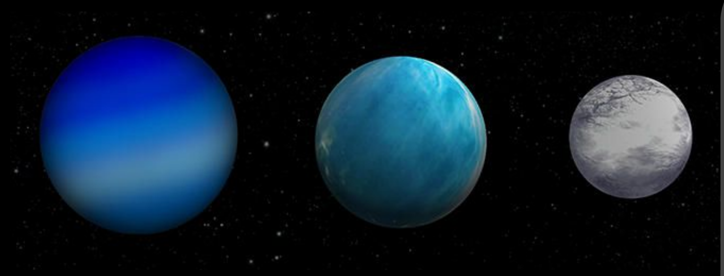
Retrieval models

Hybrid atmosphere

→

Combine retrieval analysis with models of atmospheric evolution

Population study



Extend methodology to GJ 1214b, TOI-836c, and GJ 9827d

→

Template for analyzing upcoming PLATO discoveries

esa

plato

Thank you
for your attention!

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"Therefore, innumerable are the worlds and infinite the earths that orbit around those suns as we see the seven orbiting our Sun"

Giordano Bruno
(1548-1600)