

The cloudy climate of HATS-6b

Sven Kiefer

KU Leuven, OEAW IWF, and TU Graz

N. Bach-Møller, D. Samra, D. A. Lewis, A. D. Schneider, F. Amadio,
H. Lecoq Molinos, L. Decin, L. Carone, U. Jørgensen, Ch. Helling

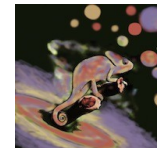
KU LEUVEN

ÖAW

ÖSTERREICHISCHE
AKADEMIE DER
WISSENSCHAFTEN

IWF
INSTITUT FÜR
WELTRAUMFORSCHUNG

TU
Graz



How we model the atmosphere

General Circulation Models



Aaron Schneider



Ludmila Carone

Cloud formation

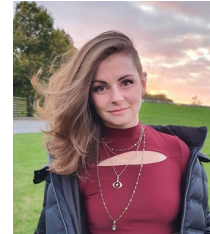


Helena Lecoq-Molinos



Dominic Samra

Chemistry



Nanna Bach-Møller



Flavia Amadio

Institutions



David Lewis



Christiane Helling



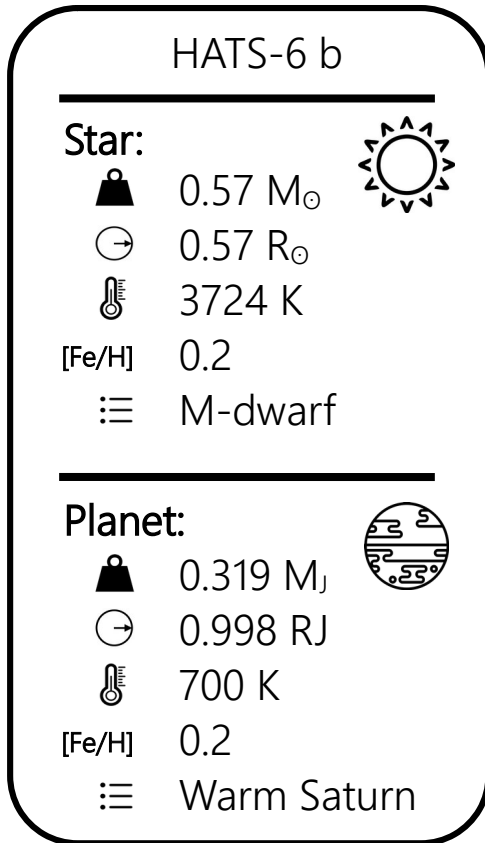
Uffe Jørgensen



Leen Decin


Why HATS-6b?


Why HATS-6b?





Why HATS-6b?

HATS-6 b


Star: 


 0.57 M_{\odot}


 0.57 R_{\odot}


 3724 K


[Fe/H] 0.2

 M-dwarf


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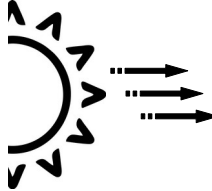
 0.319 M_J

 0.998 R_J

 700 K

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 Warm Saturn


 M-dwarfs are active


- Stellar irradiation
- Stellar energetic Particles (SEPs)


Why HATS-6b?

HATS-6 b


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
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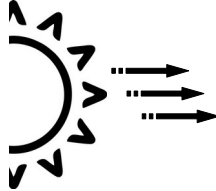
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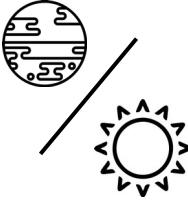
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 **M-dwarfs are small**

- Large transit depths (3.2%)
- Questions about formation


Why HATS-6b?


HATS-6 b




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
[Fe/H] 0.2

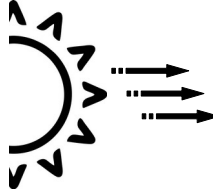
 M-dwarf

Planet: 

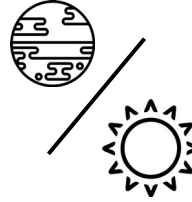
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 **HATS-6b is temperate**

- Effective Temperature ~700 K
- Global cloud coverage

How we model the atmosphere

How we model the atmosphere

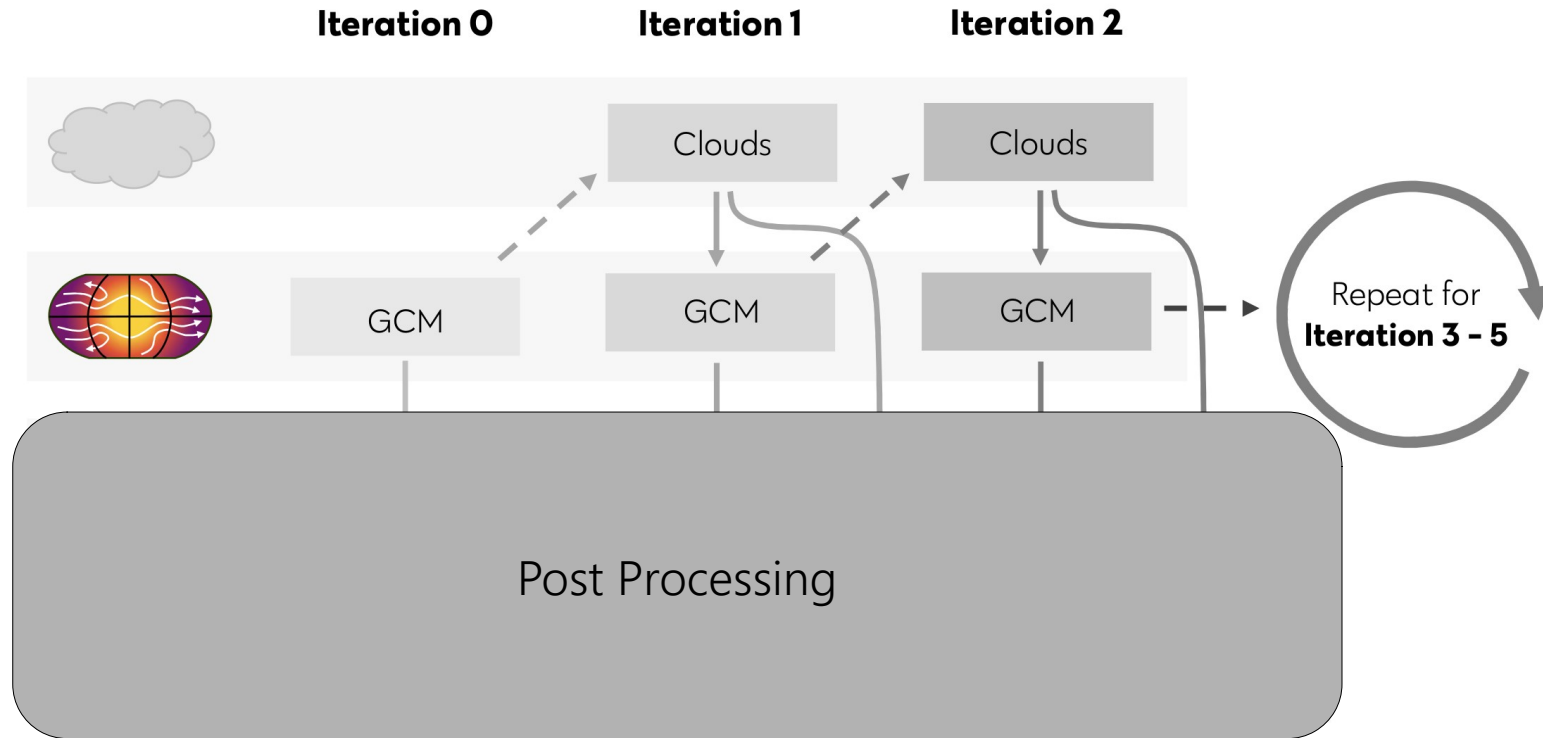
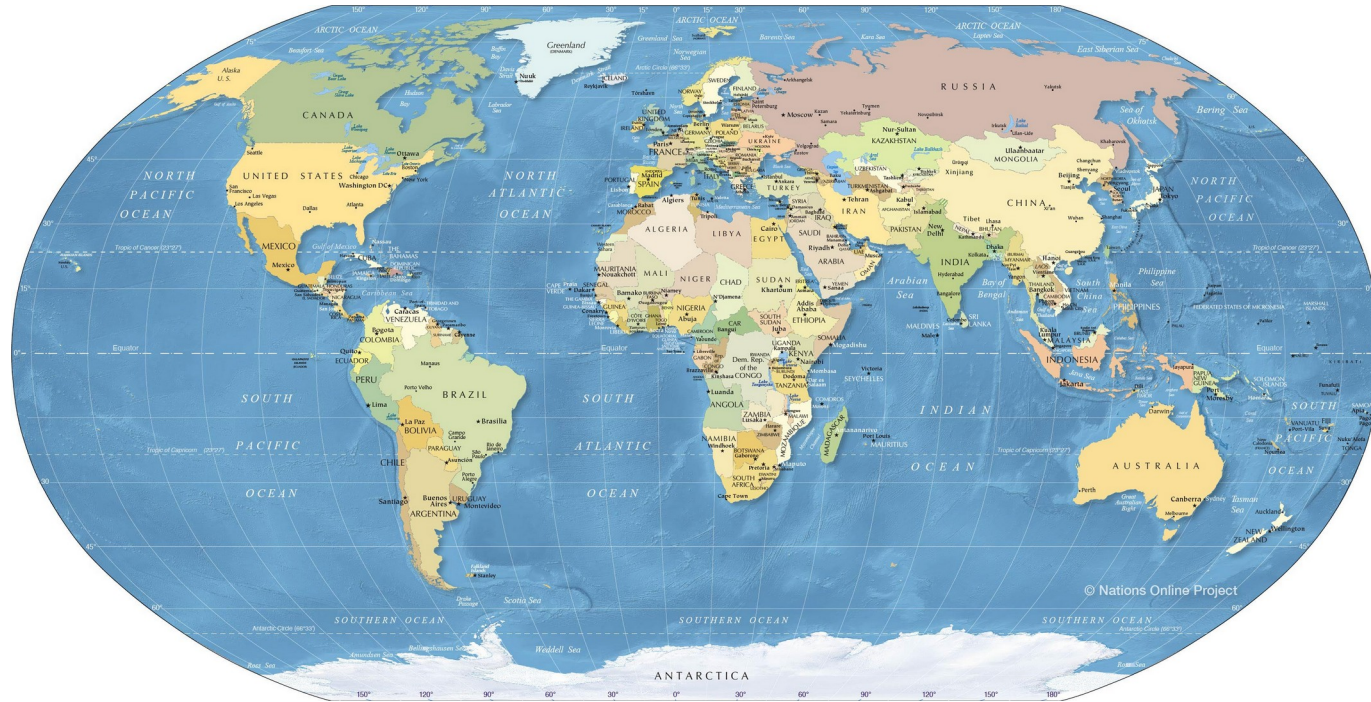
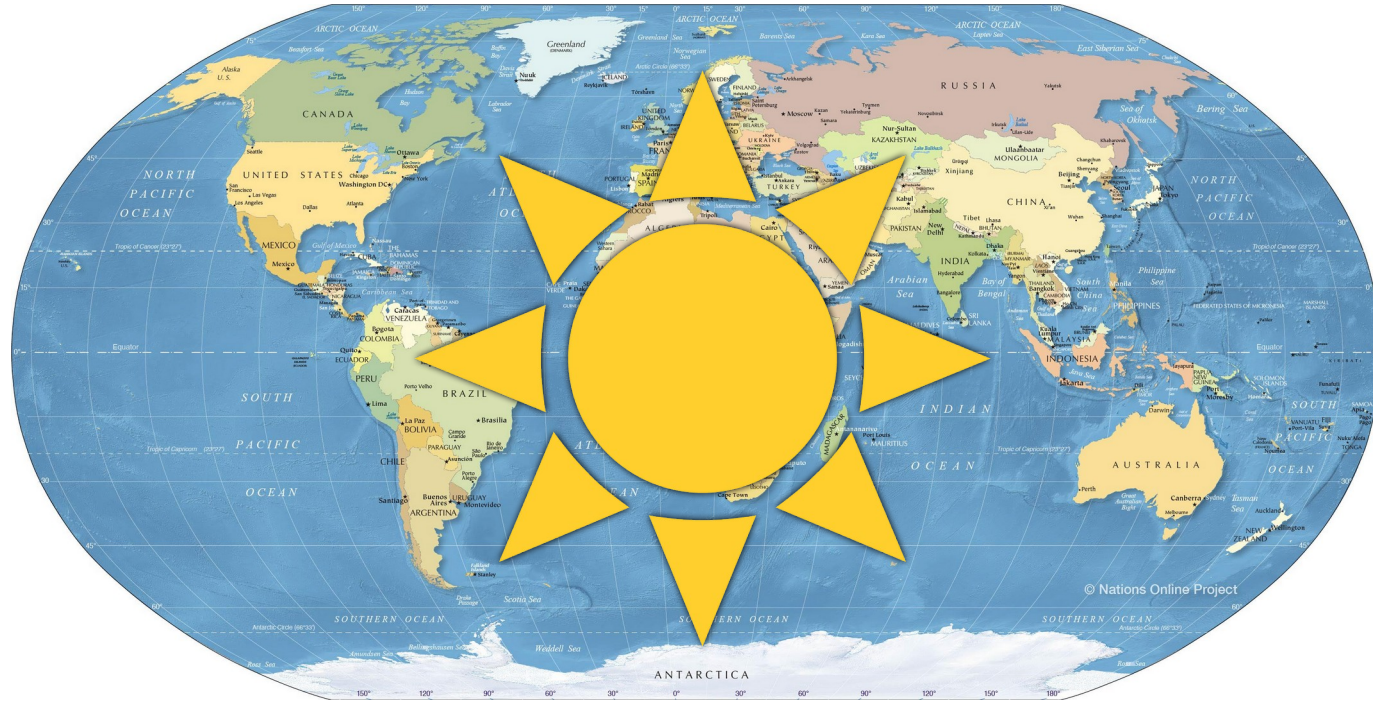


Image credit: N. Bach-Møller

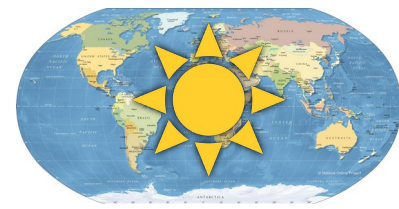
Clouds in 3D



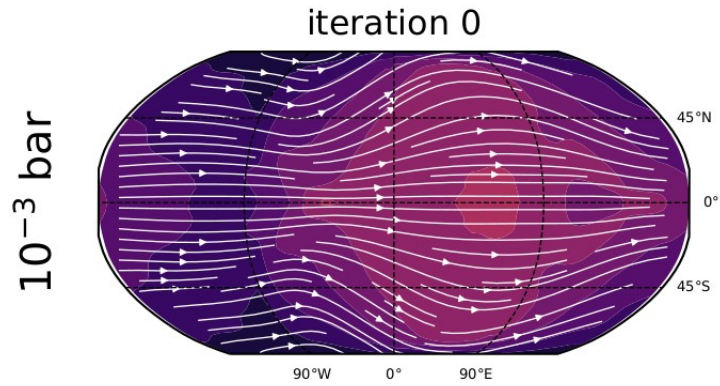
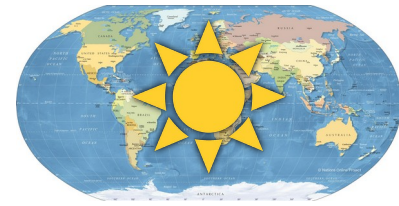
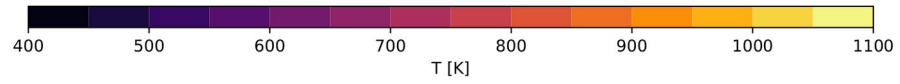
Clouds in 3D



Clouds in 3D



Clouds in 3D



Clouds in 3D – Kinetic cloud formation

Clouds in 3D – Kinetic cloud formation

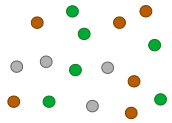


Image altered from Helling (2018)

Clouds in 3D – Kinetic cloud formation

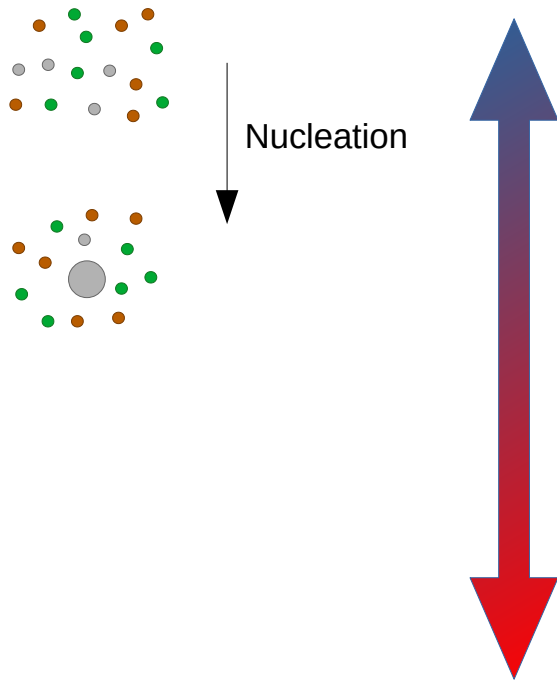


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Clouds in 3D – Kinetic cloud formation

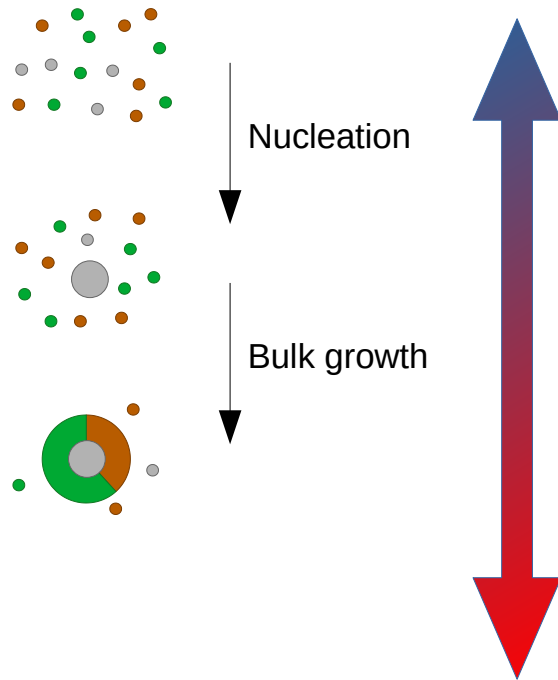
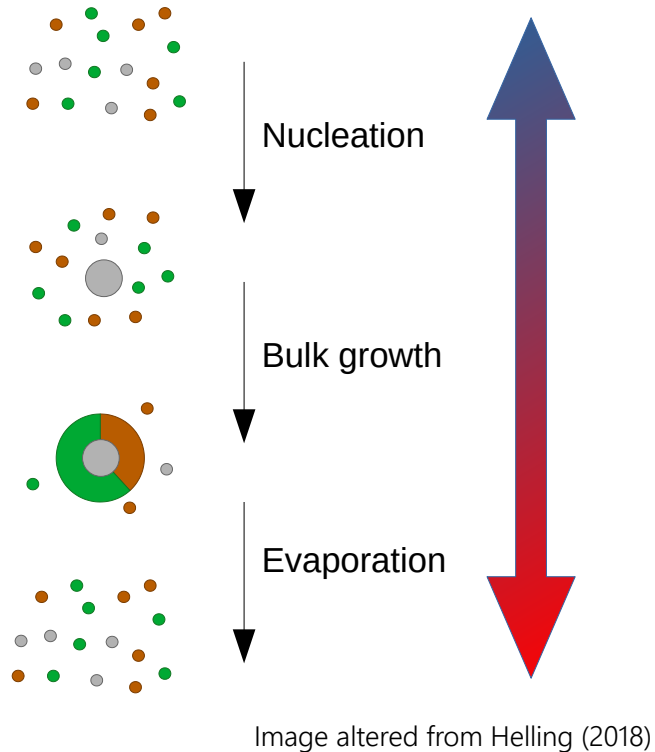
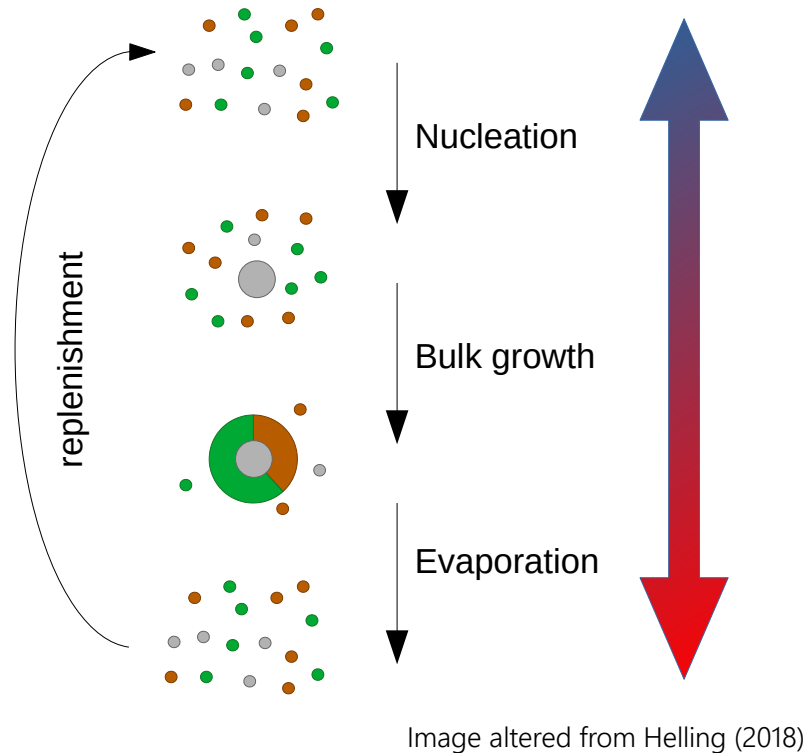


Image altered from Helling (2018)

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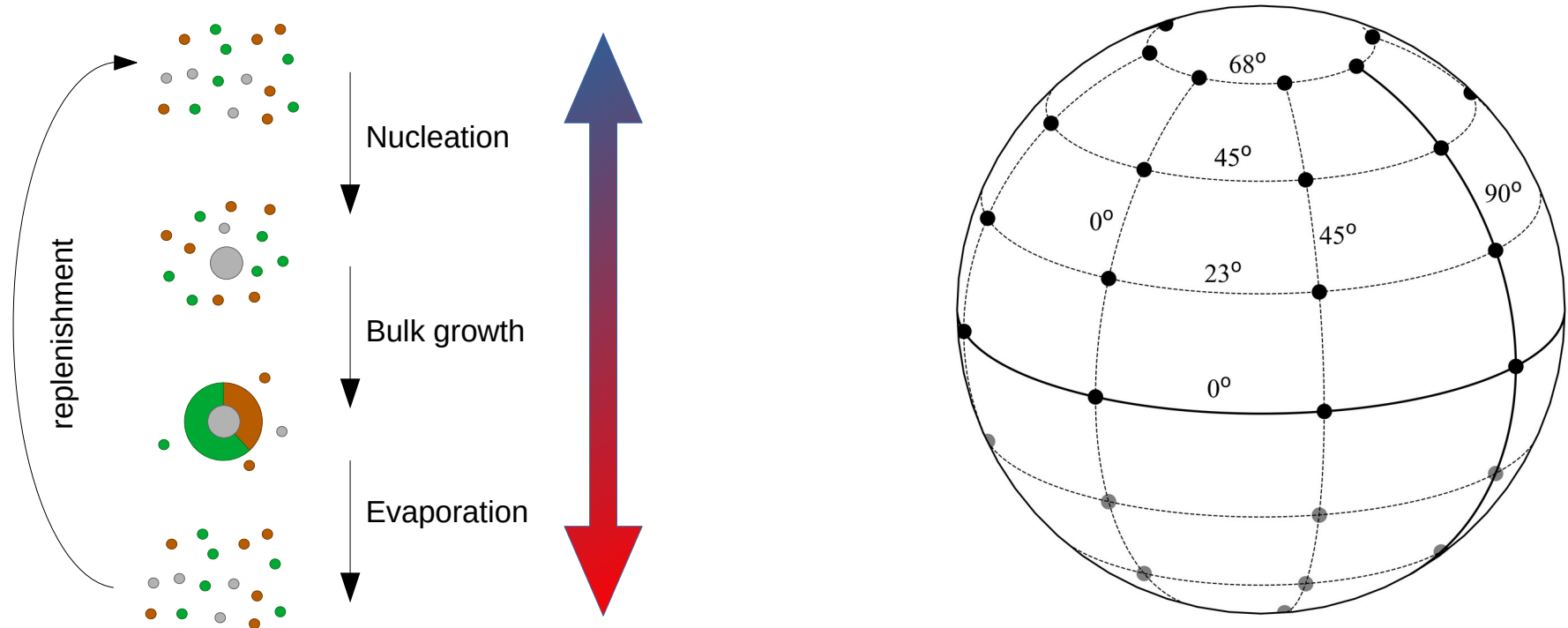
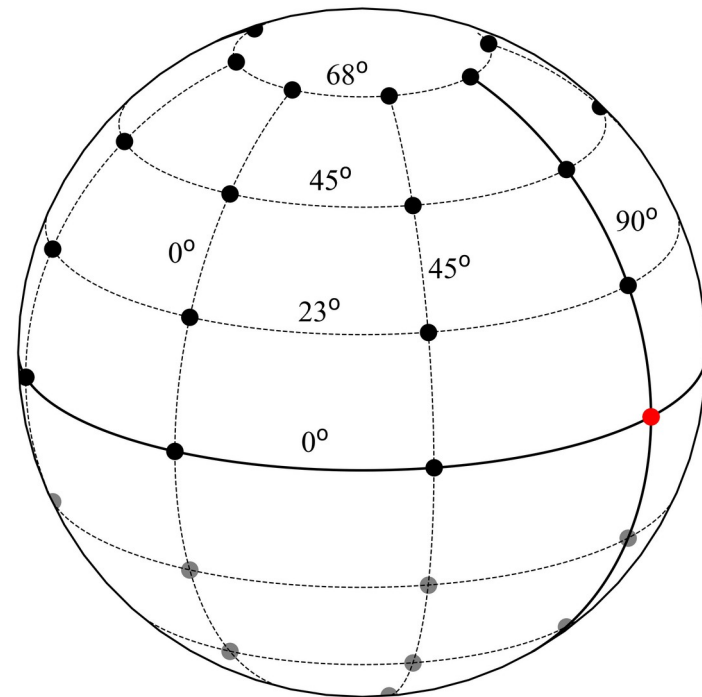
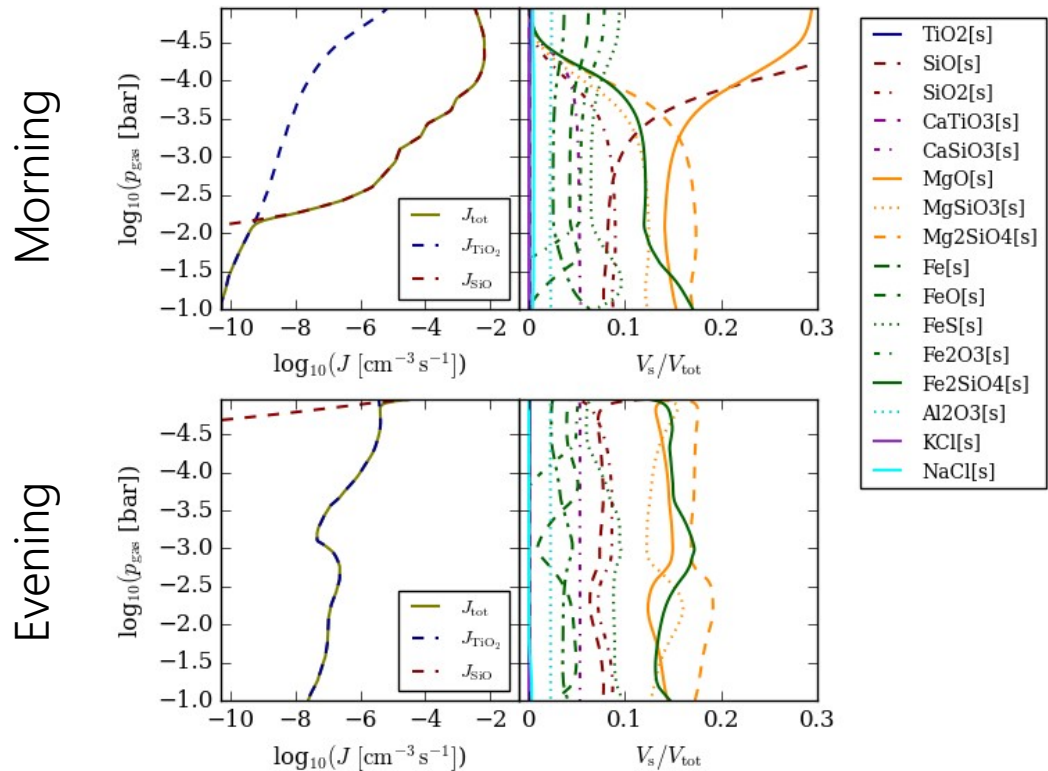
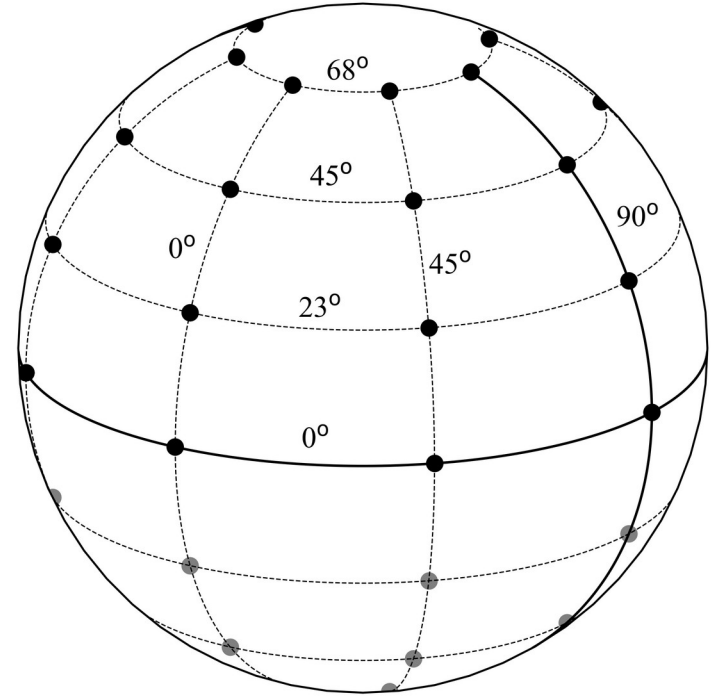
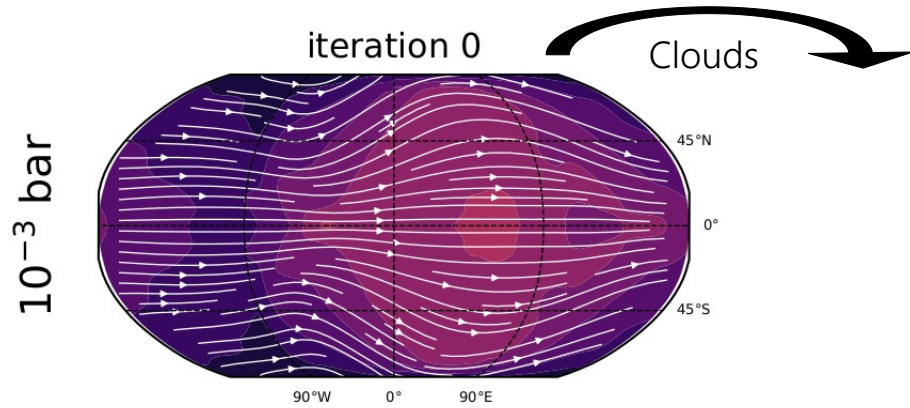
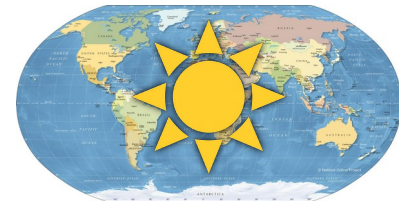
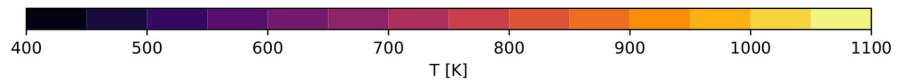


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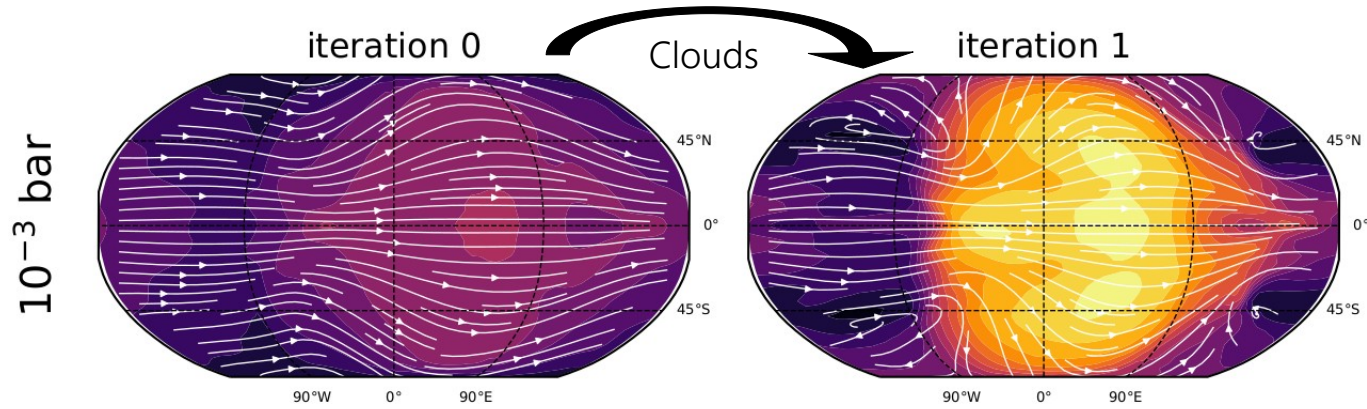
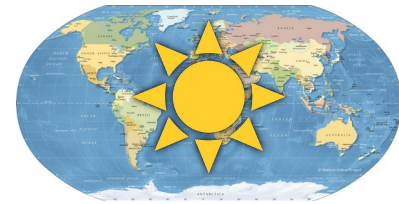
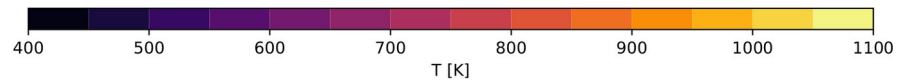
Clouds in 3D – Kinetic cloud formation



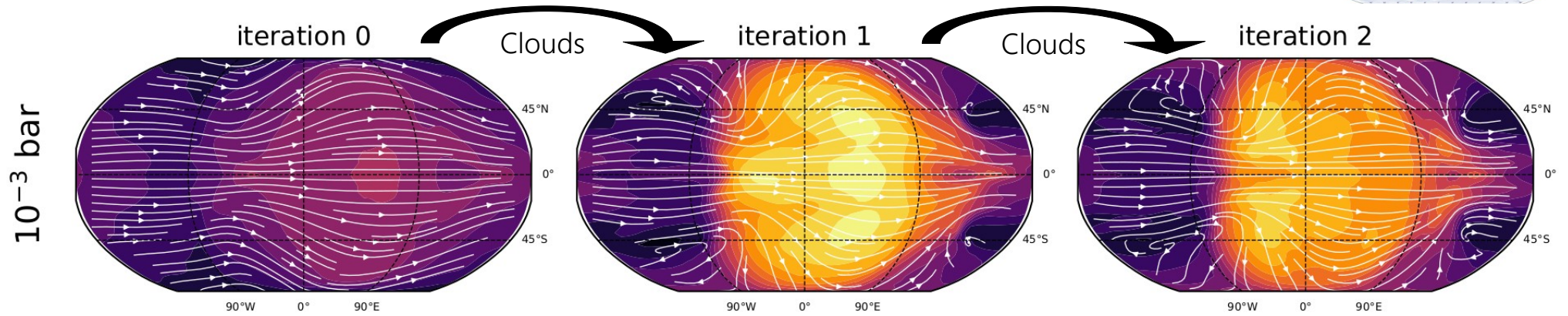
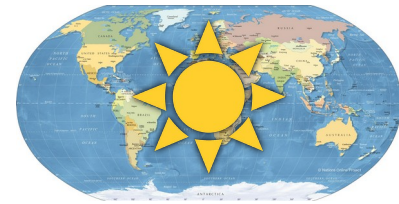
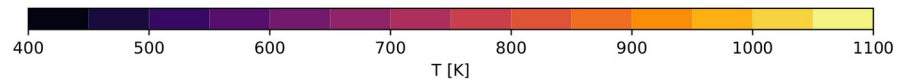
Clouds in 3D



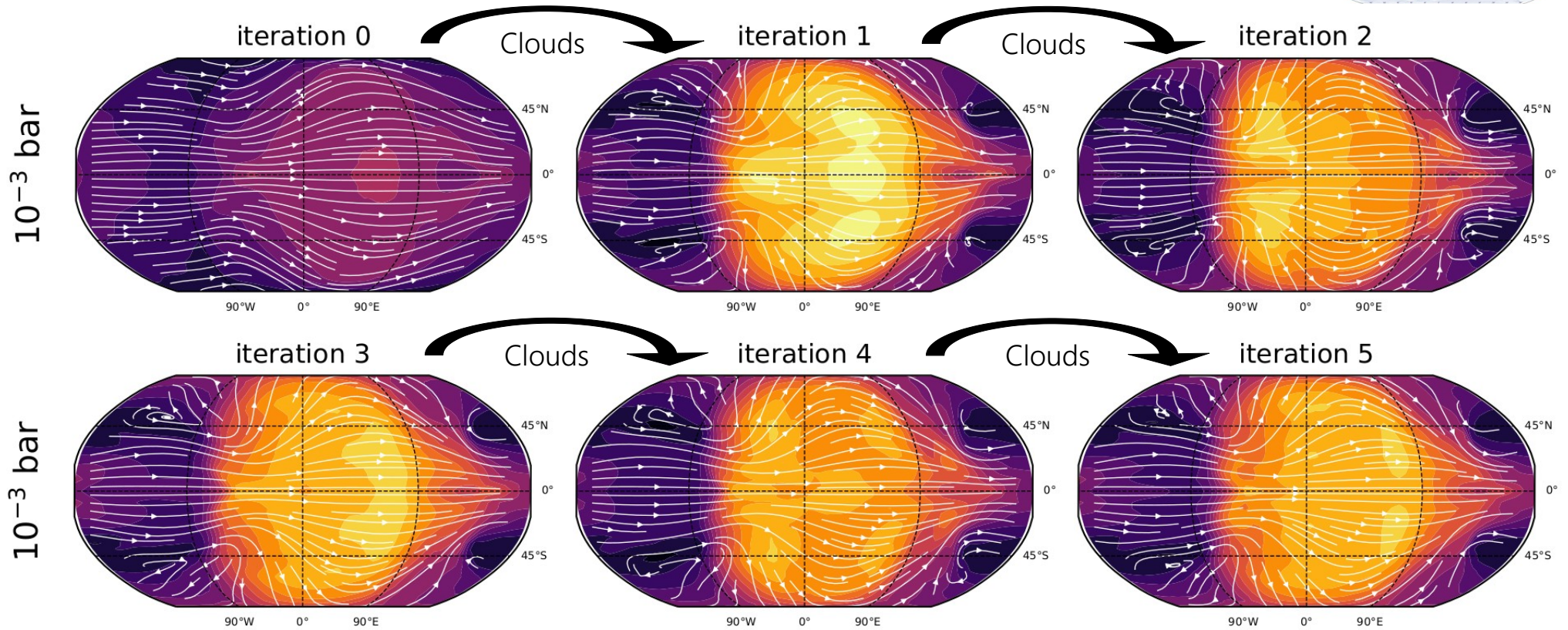
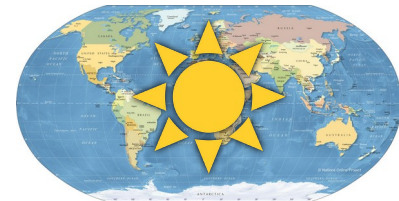
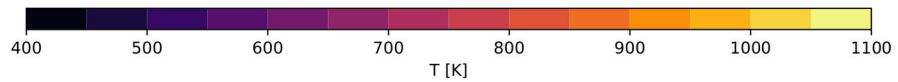
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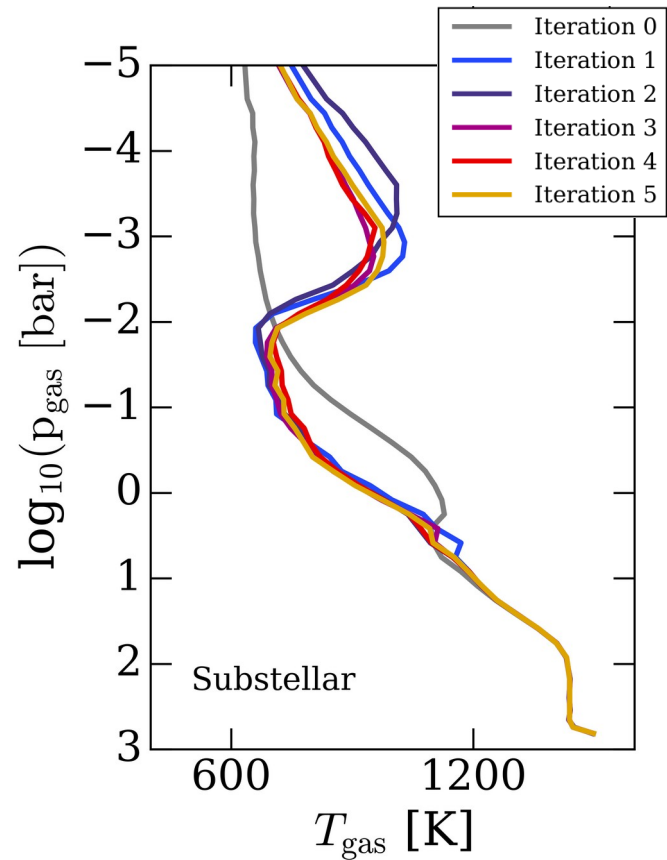
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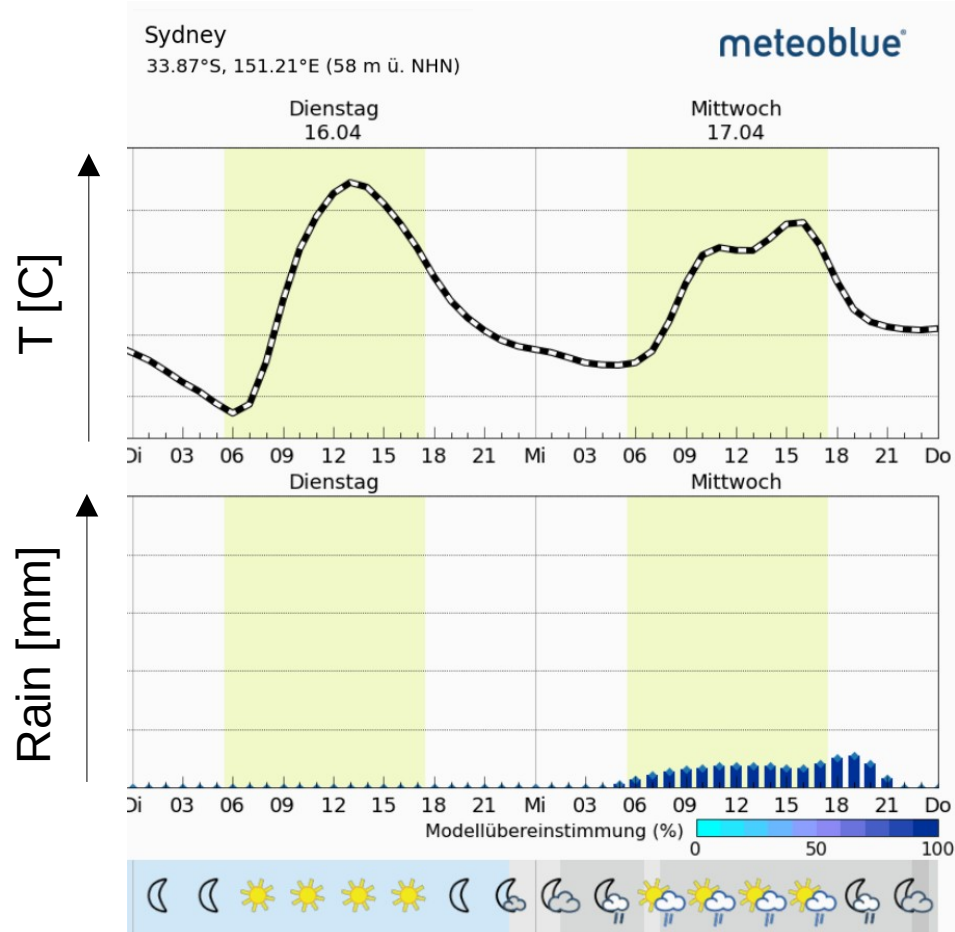
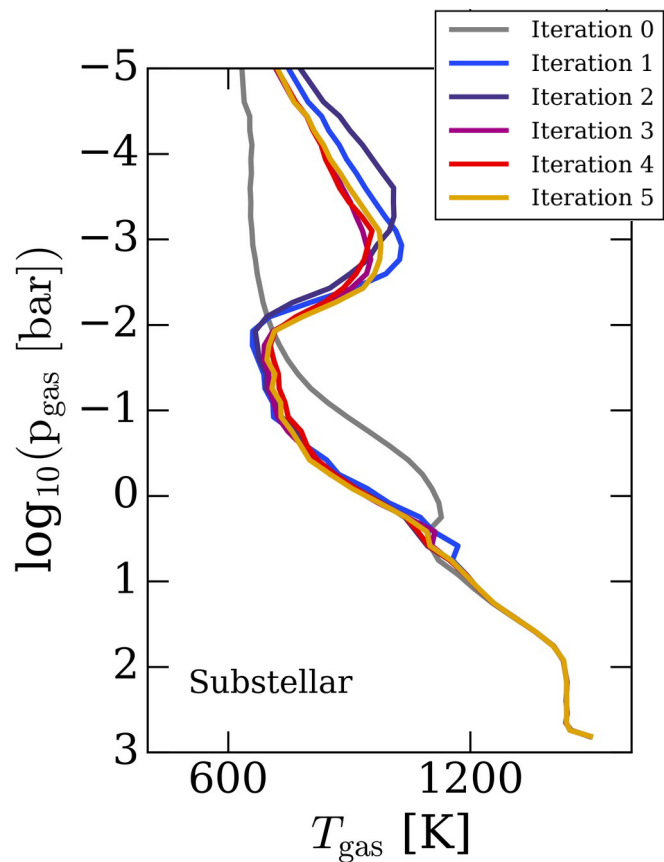
Clouds in 3D



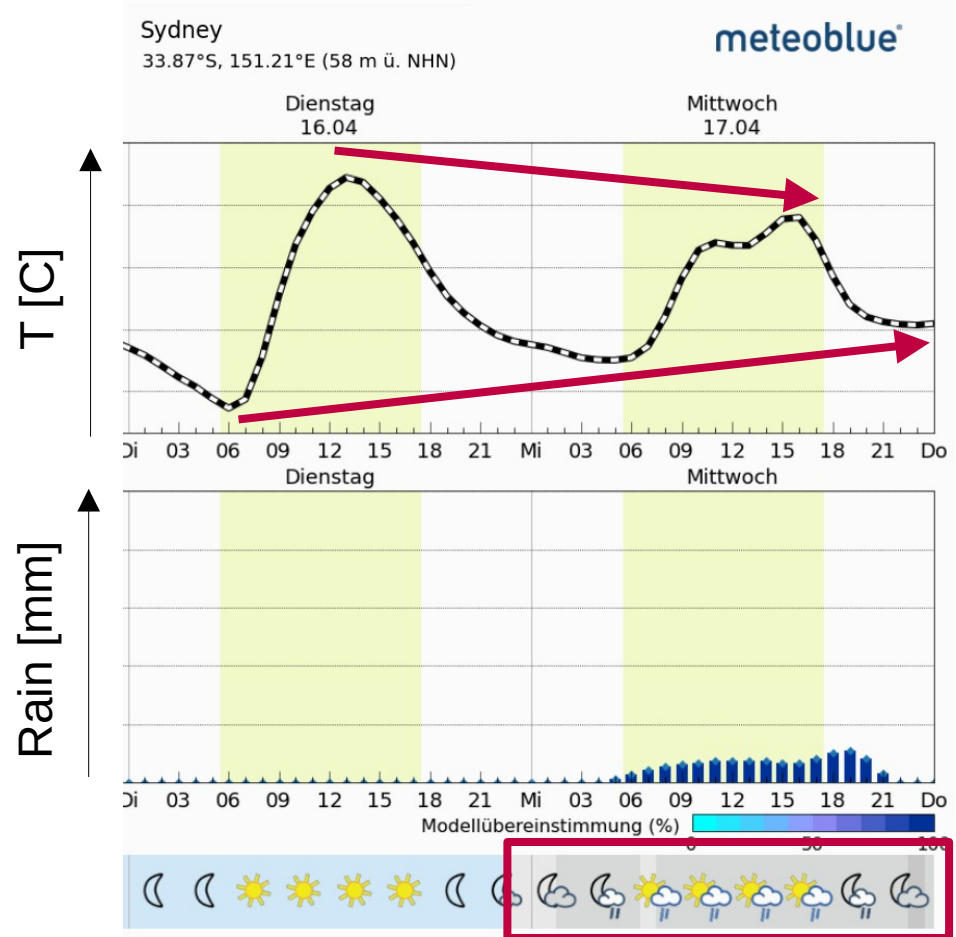
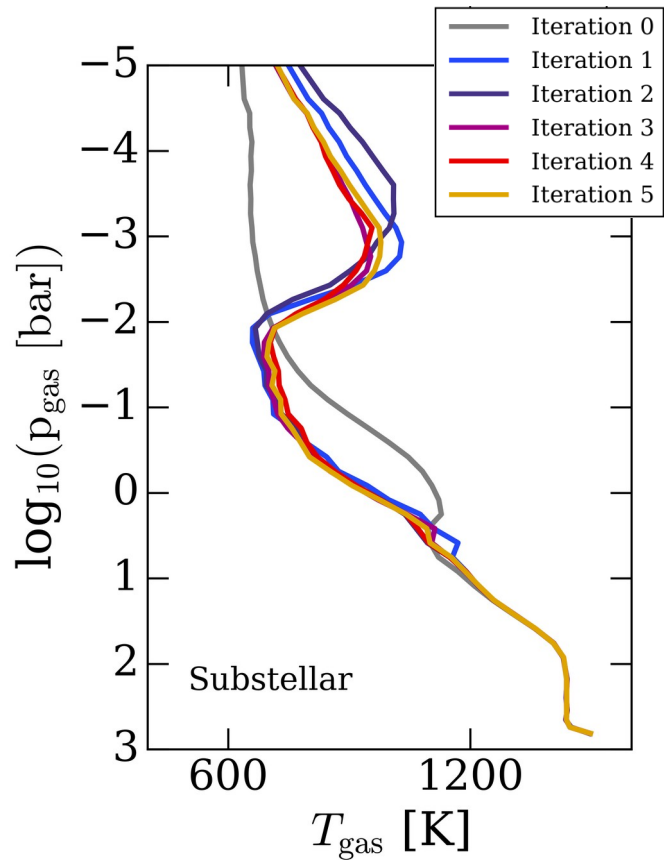
Clouds in 3D



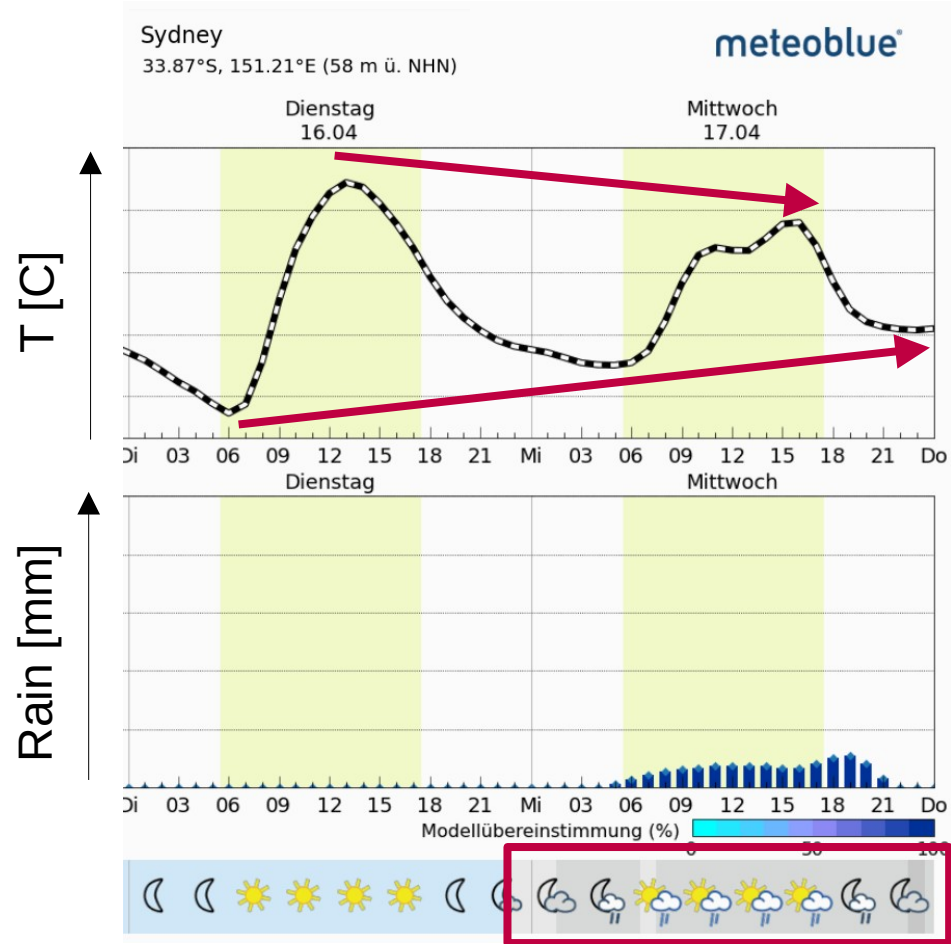
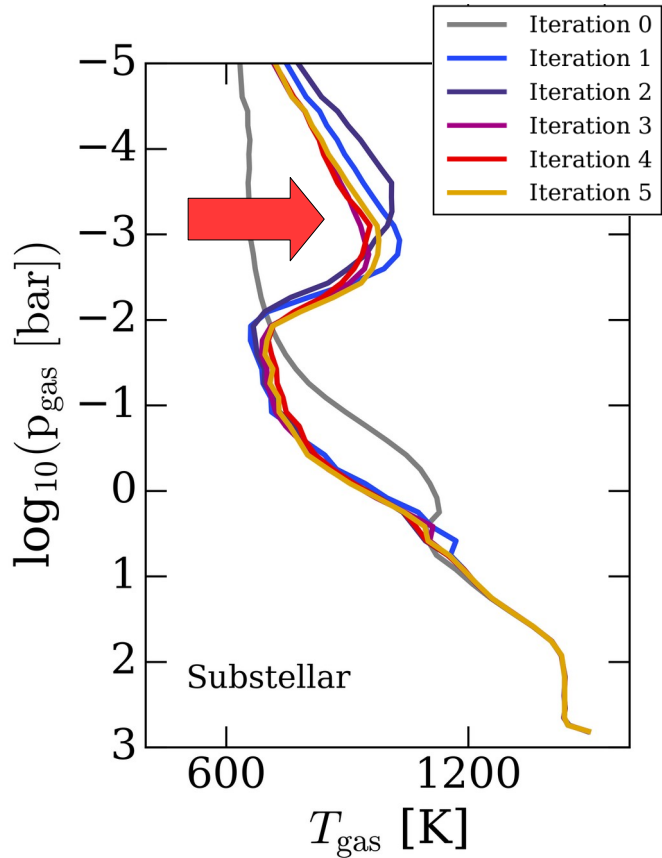
Clouds in 3D



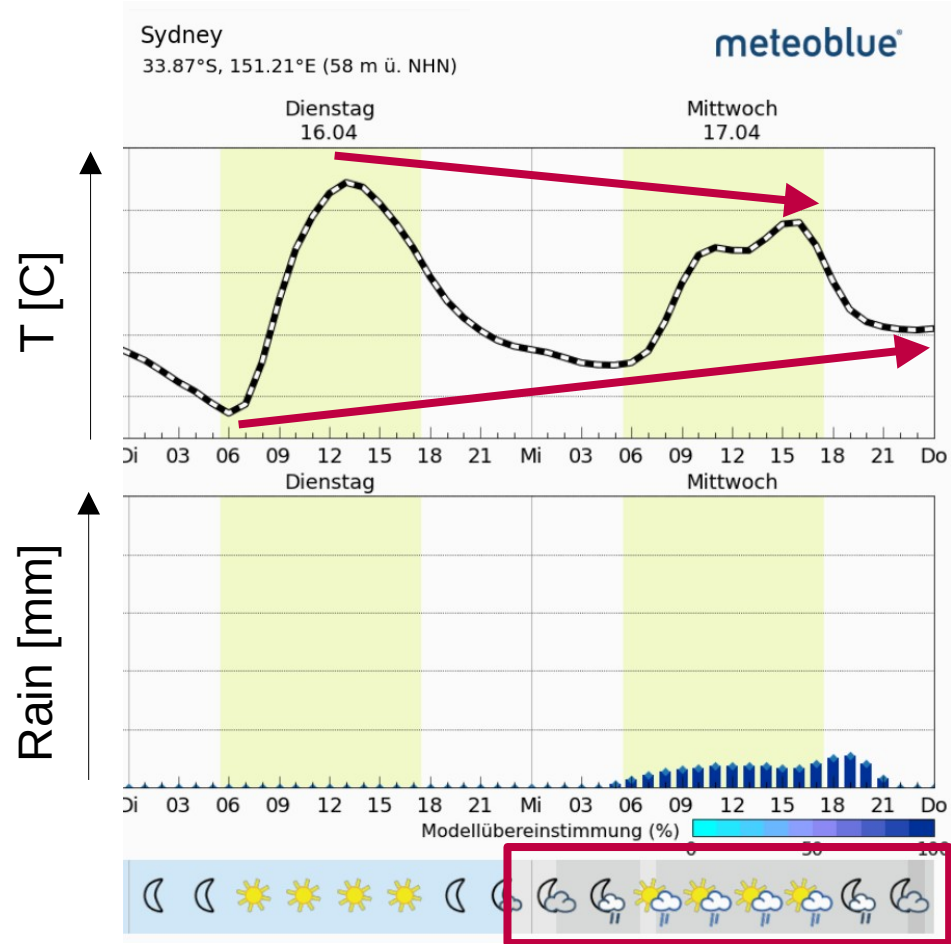
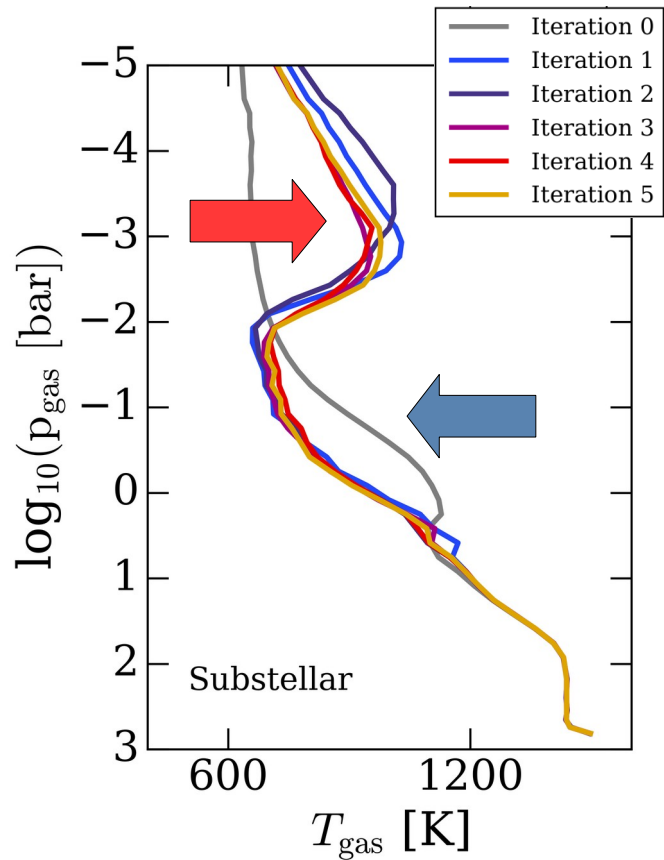
Clouds in 3D



Clouds in 3D



Clouds in 3D



How we model the atmosphere

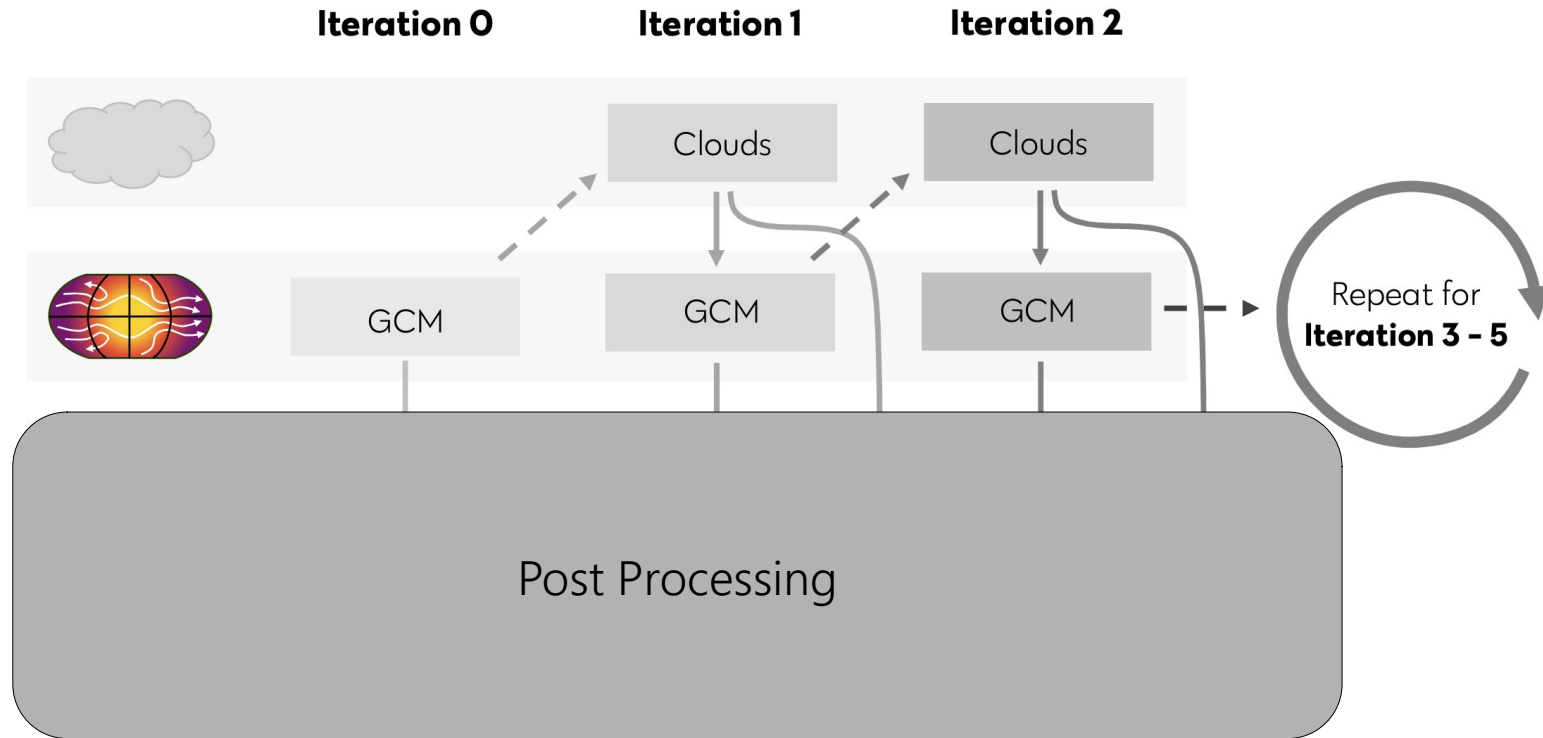


Image credit: N. Bach-Møller

How we model the atmosphere

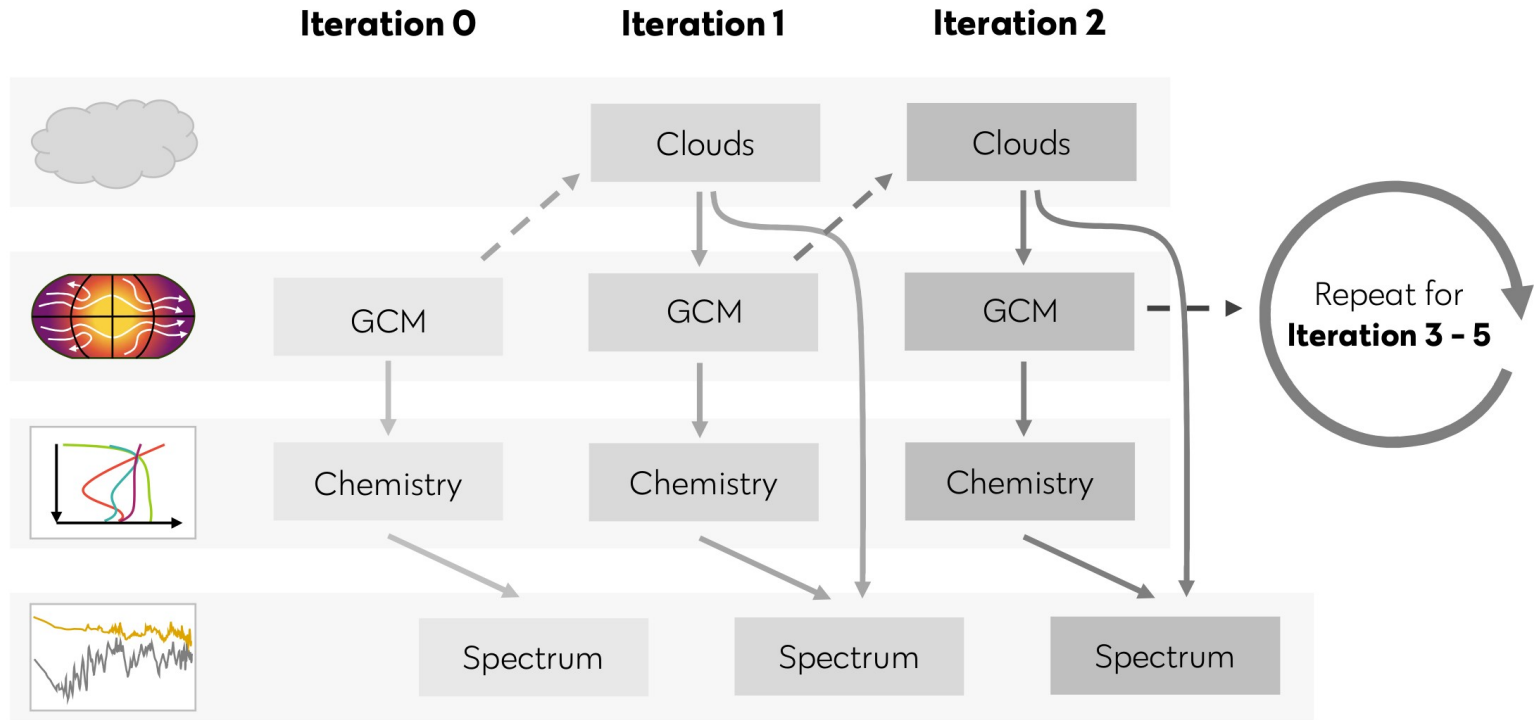
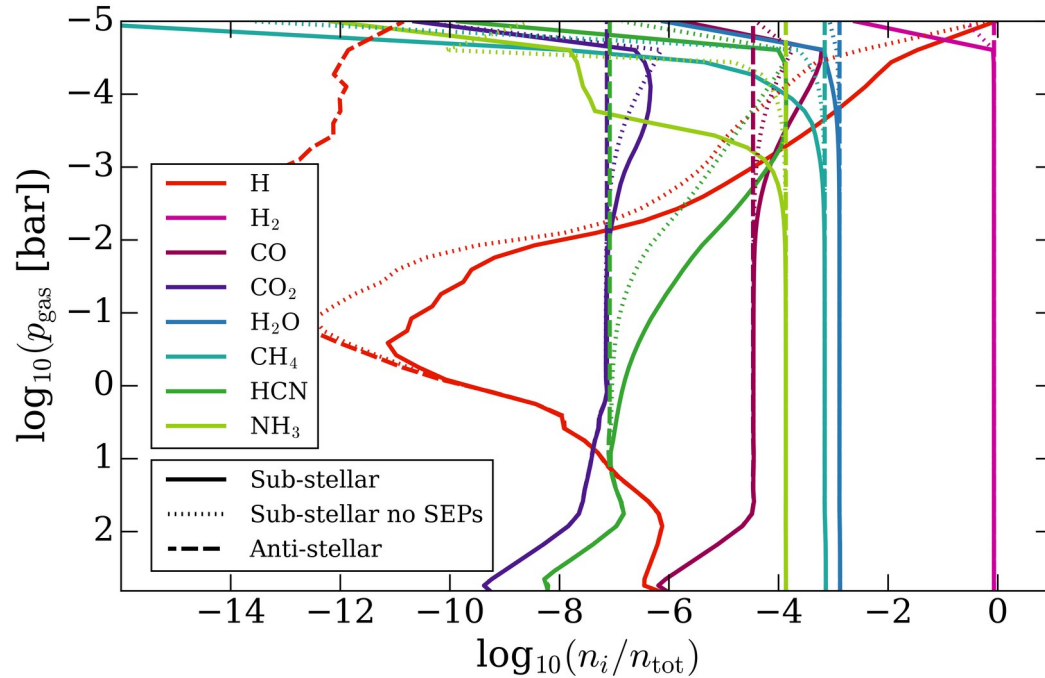
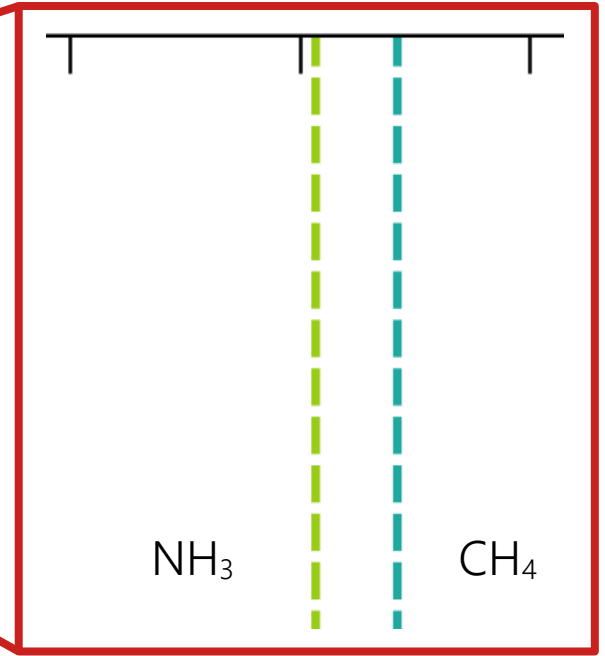
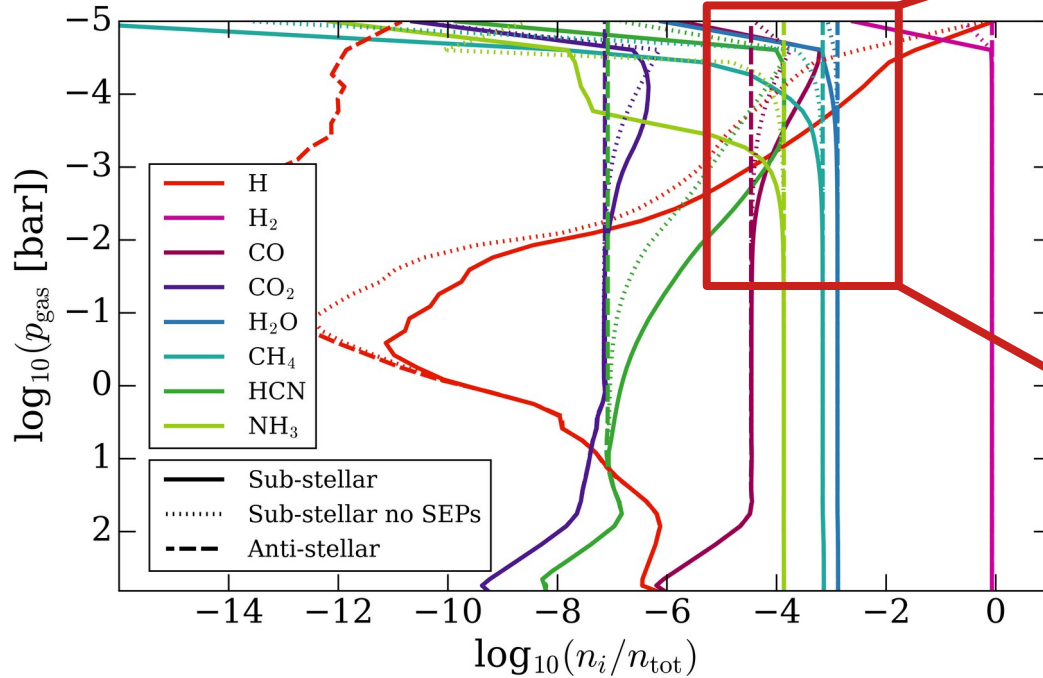


Image credit: N. Bach-Møller

Kinetic gas-phase chemistry

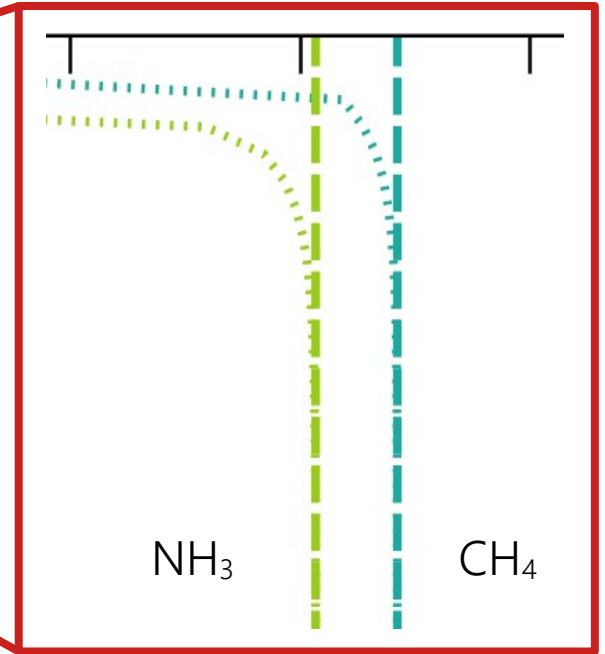
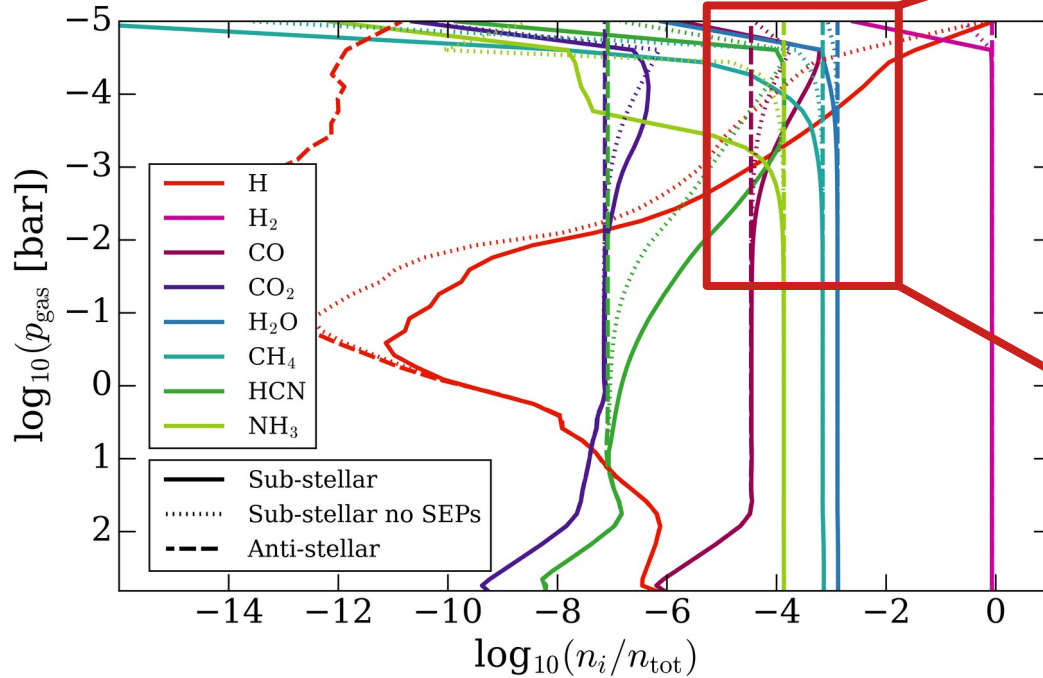


Kinetic gas-phase chemistry



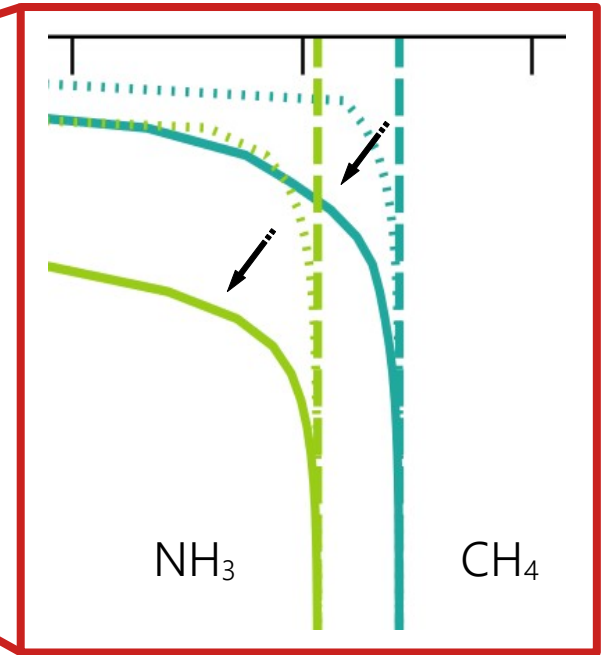
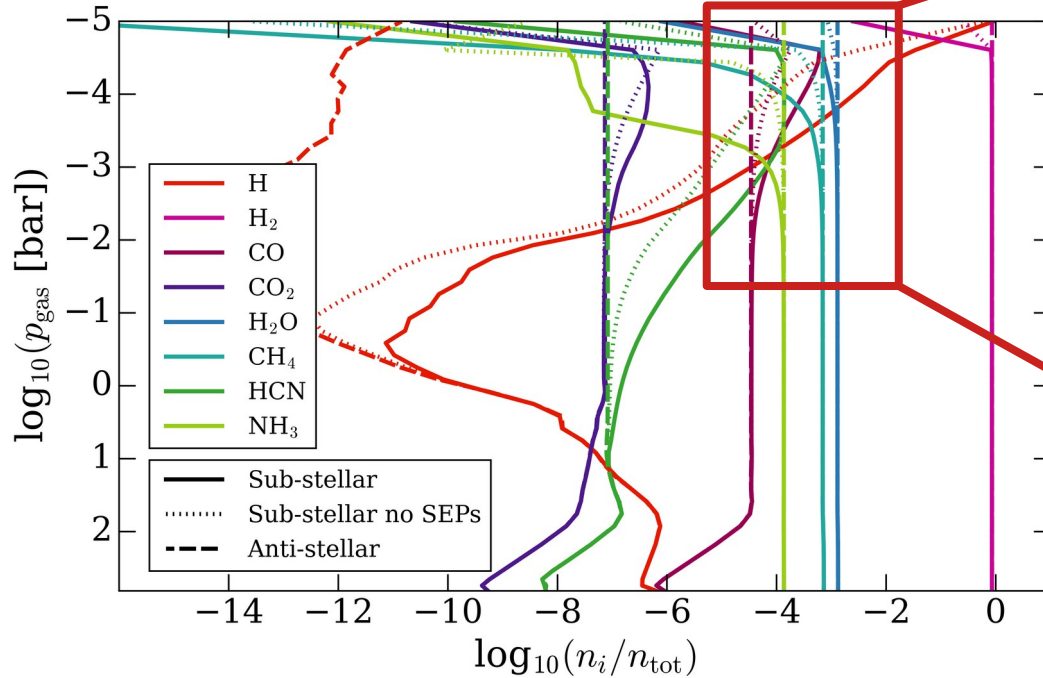
Thermal chemistry

Kinetic gas-phase chemistry



Thermal chemistry
+ XUV photo-chemistry

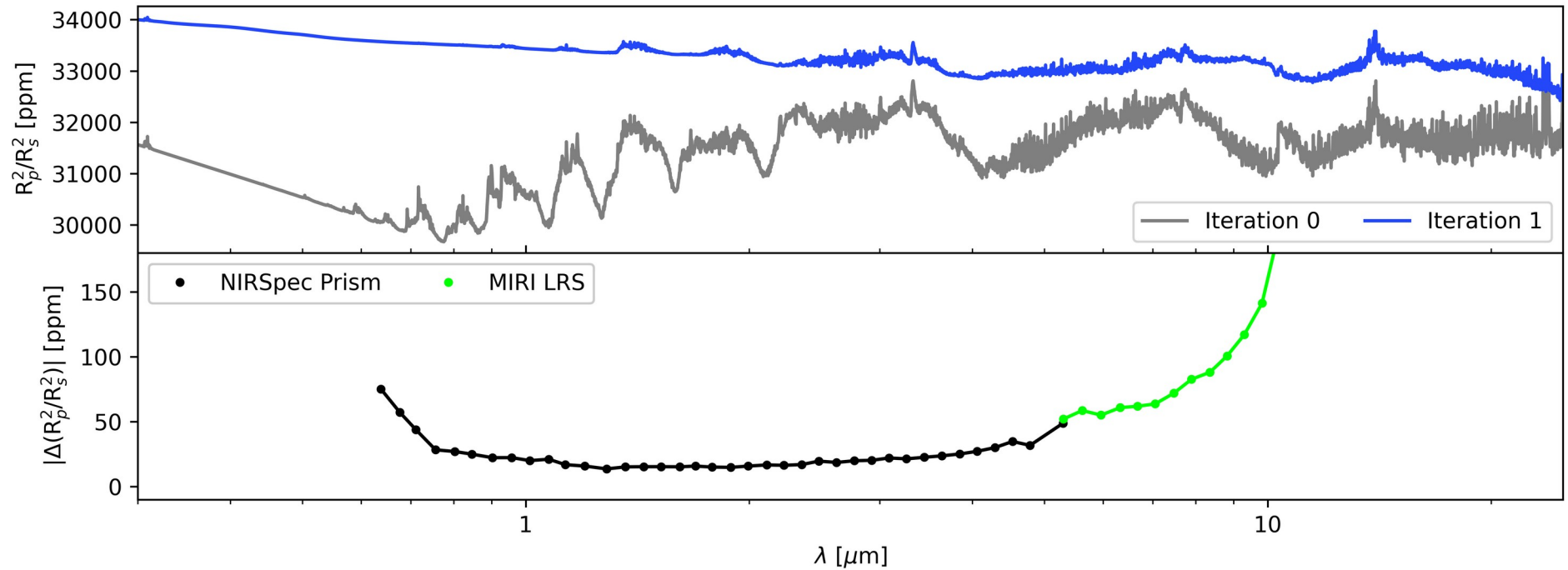
Kinetic gas-phase chemistry



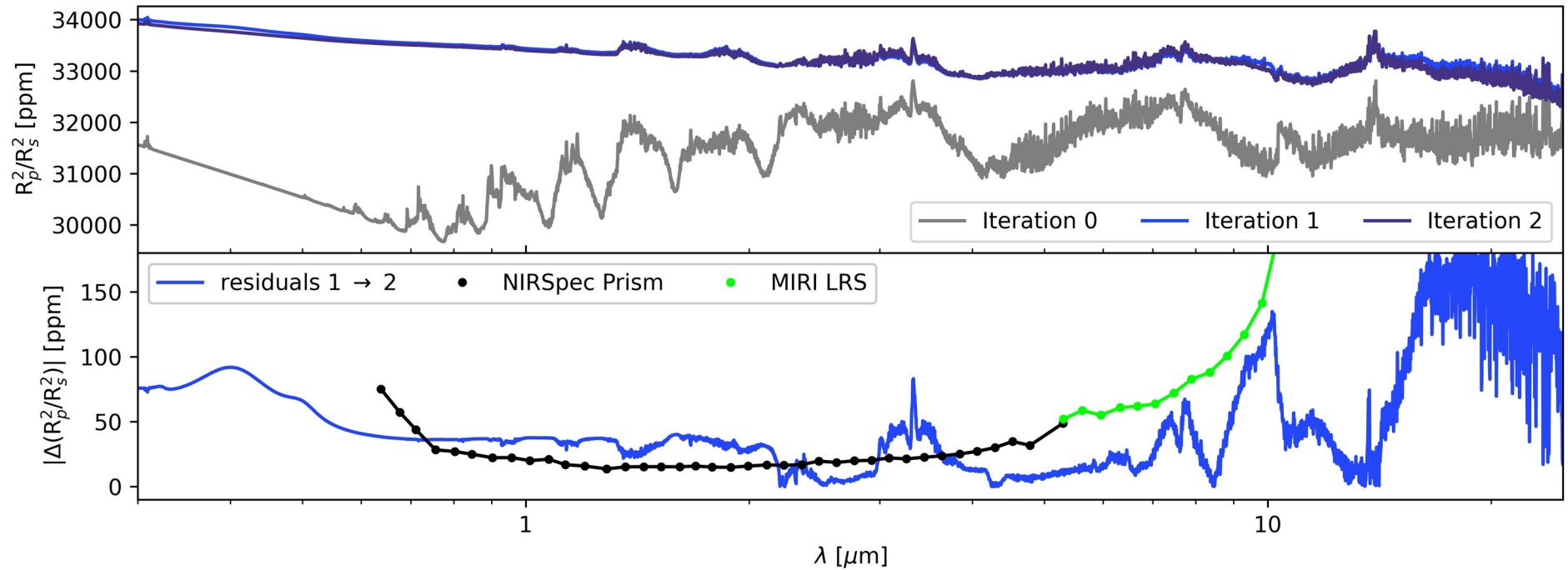
Thermal chemistry
+ XUV photo-chemistry
+ Stellar energetic particles

What can we observe?

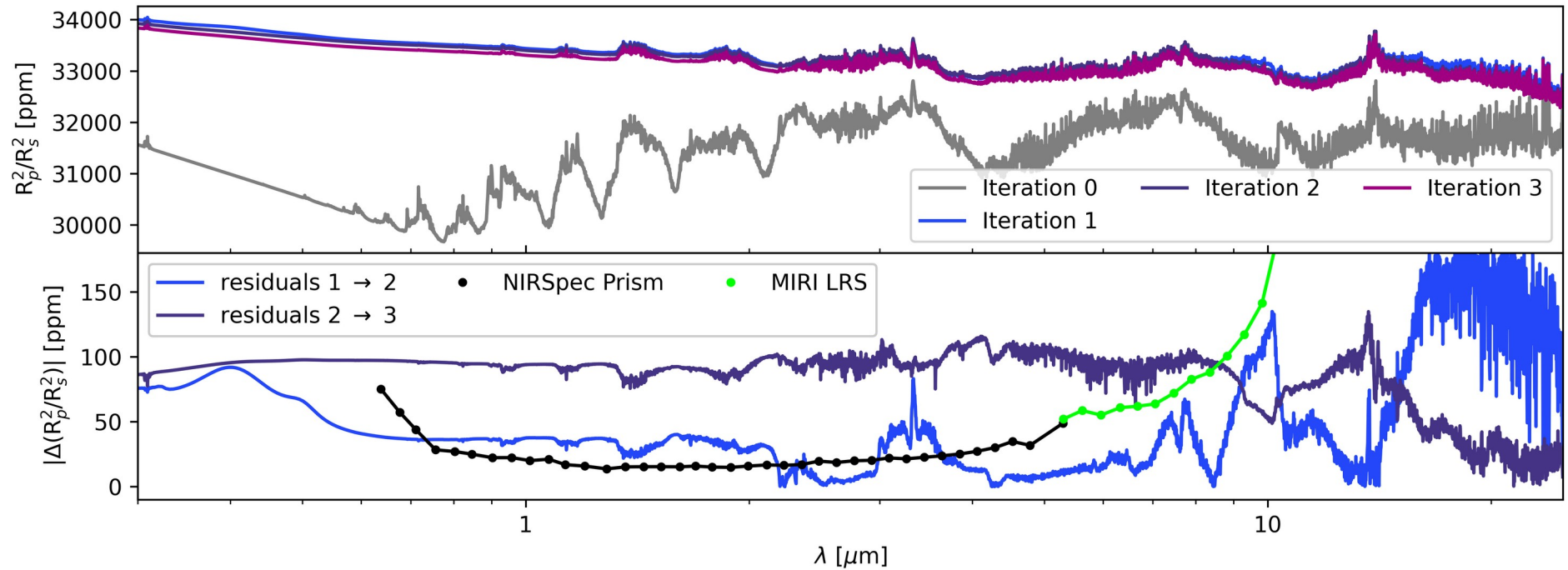
Is it observable?



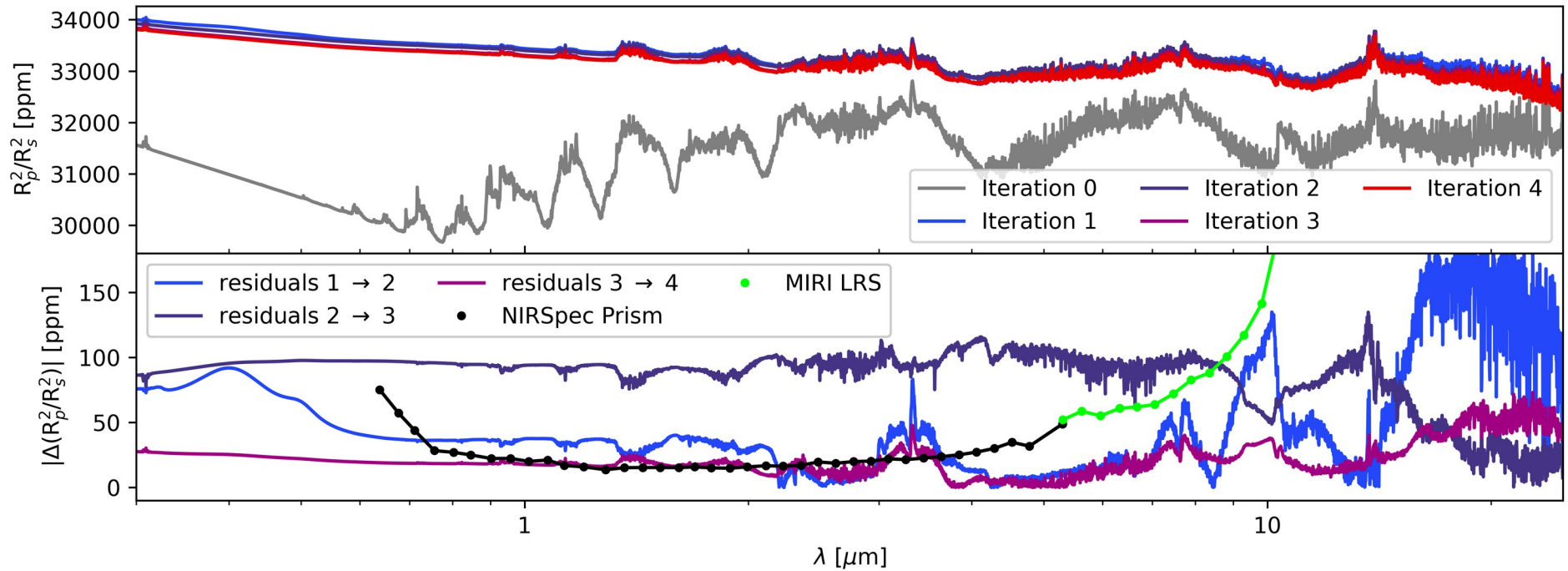
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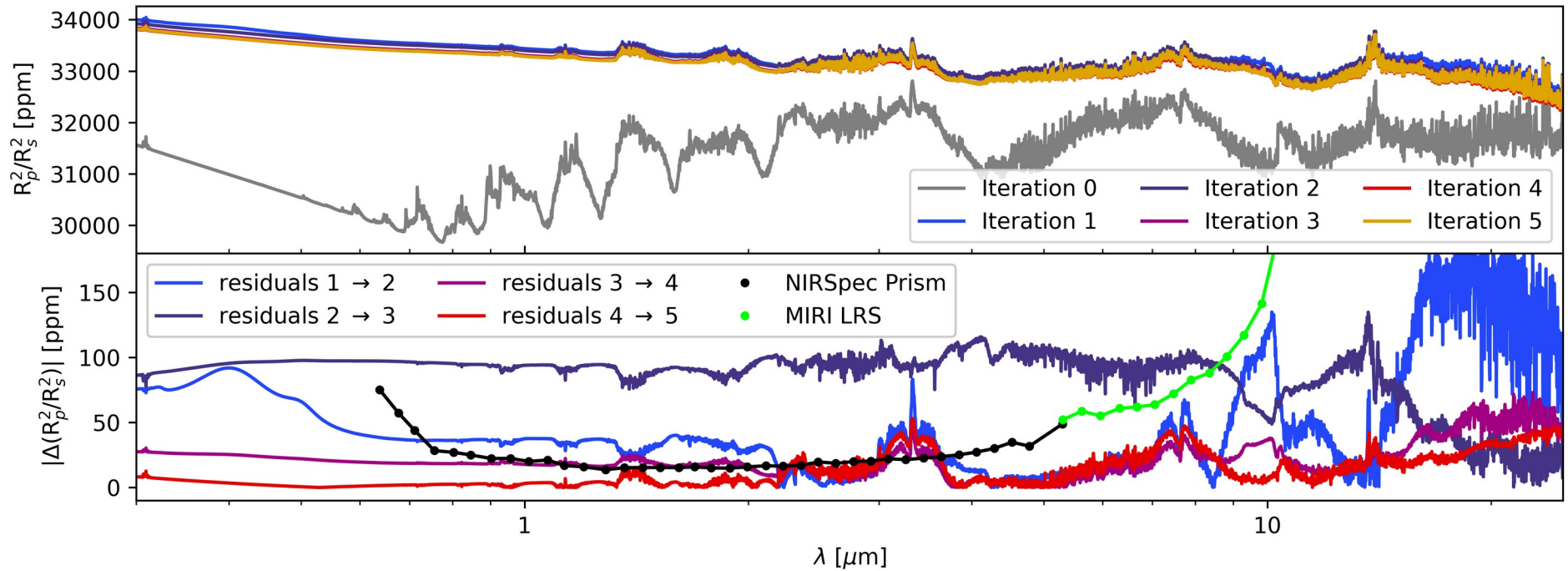
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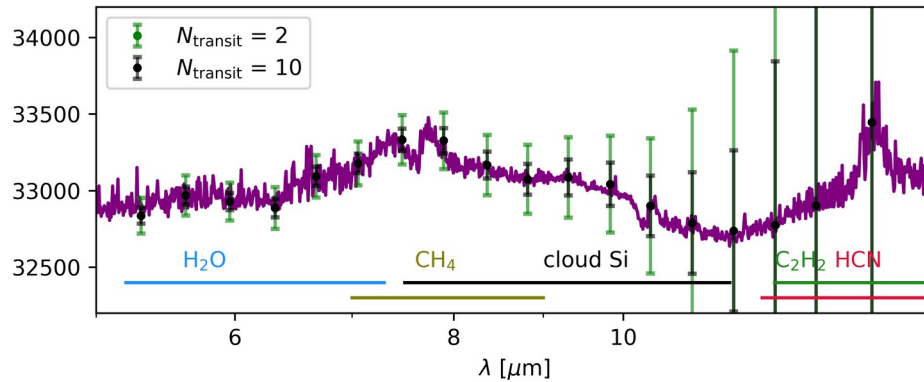
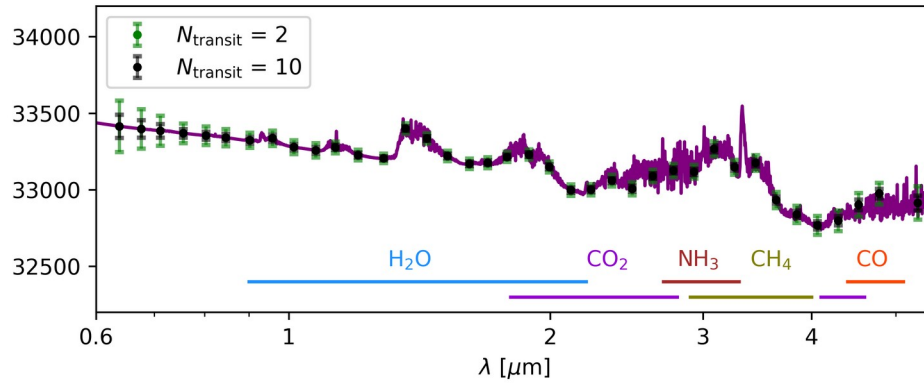
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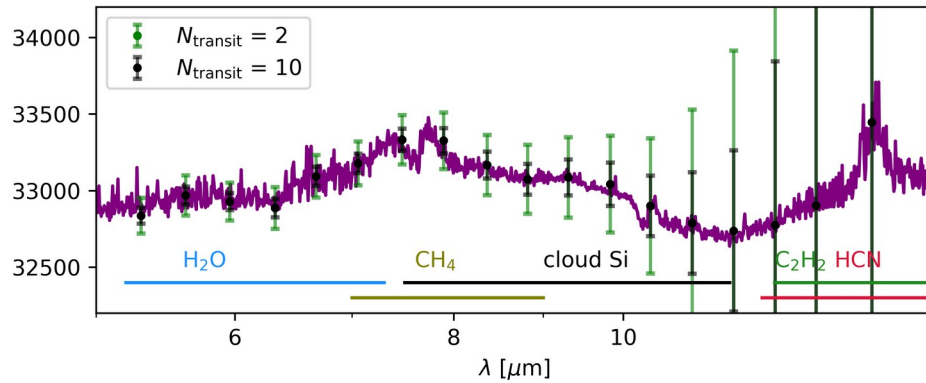
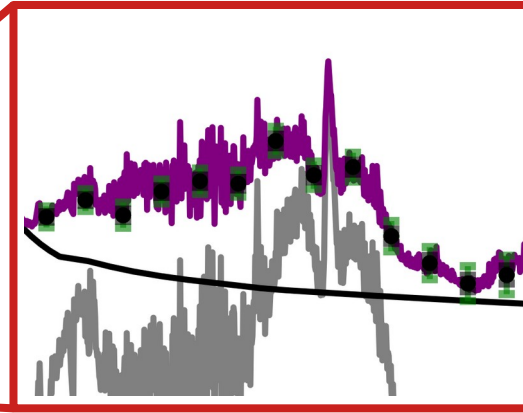
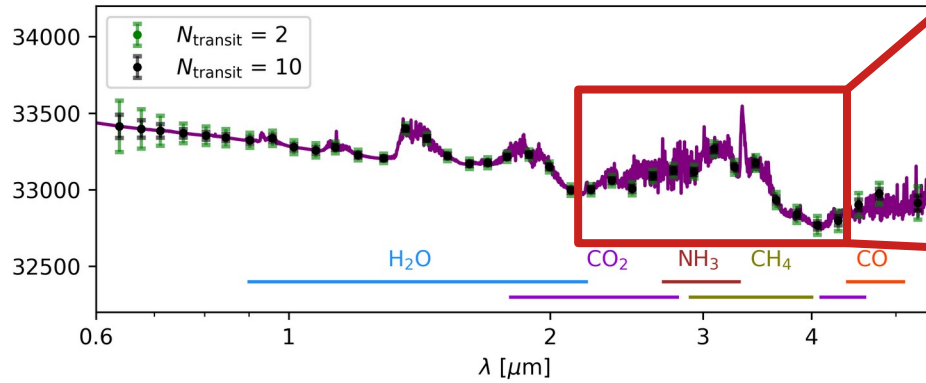
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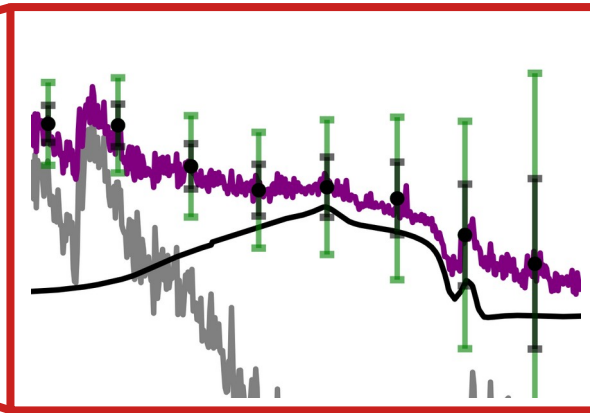
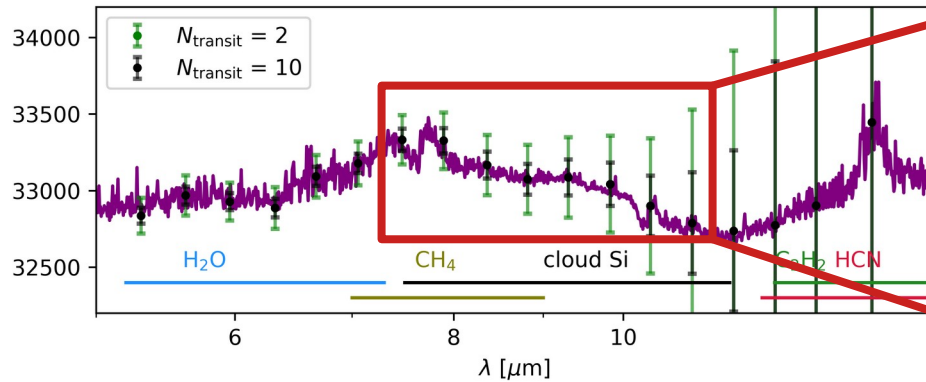
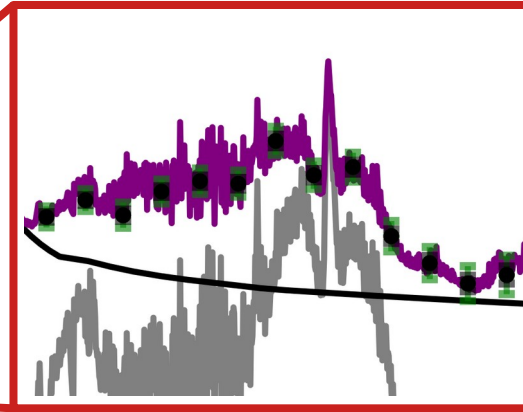
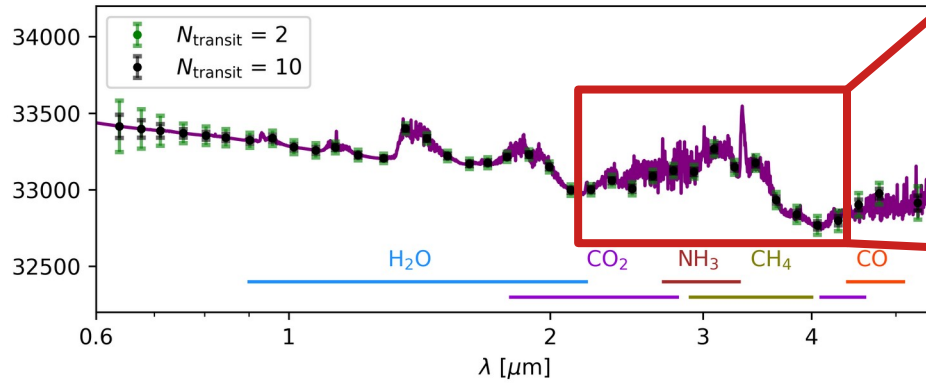
Observing HATS-6b



Observing HATS-6b



Observing HATS-6b



Summary



HATS-6 b

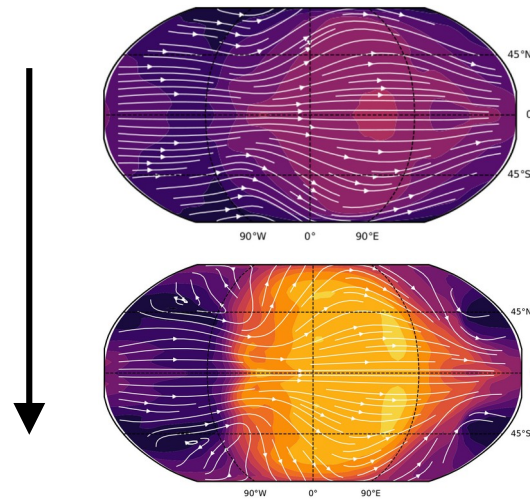
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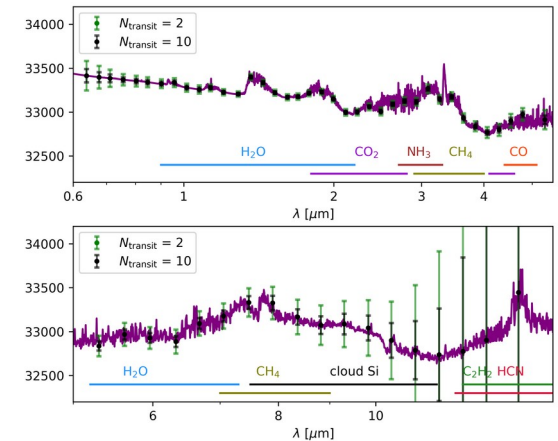
Planet:

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Clouds impact the climate

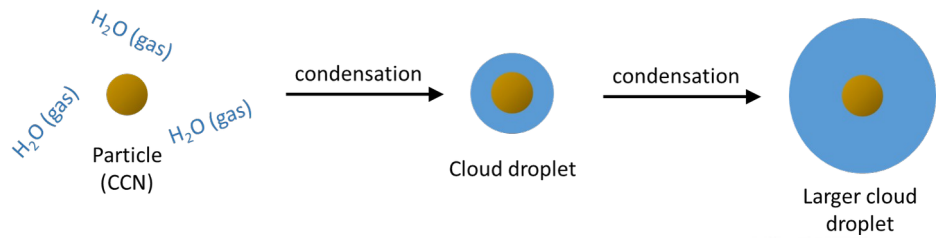


CH₄ and clouds might be observed in HATS-6b



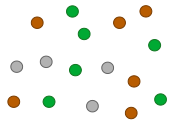
Additional Slides

Clouds on Earth

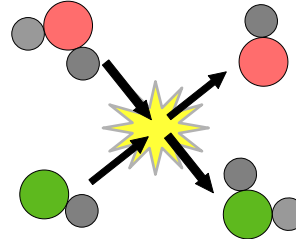


Top Image: Aerosols Department Of Physics And Astronomy Uppsala
Bottom Image: BBC science focus, Alexandra Franklin-Cheung

Cloud formation



Kinetic Chemistry



For this study:

- Elements: N, C, H, O
- Additional: Ti, Si
- 69 species
- 780 reactions

Image altered from Helling (2018)

Cloud formation

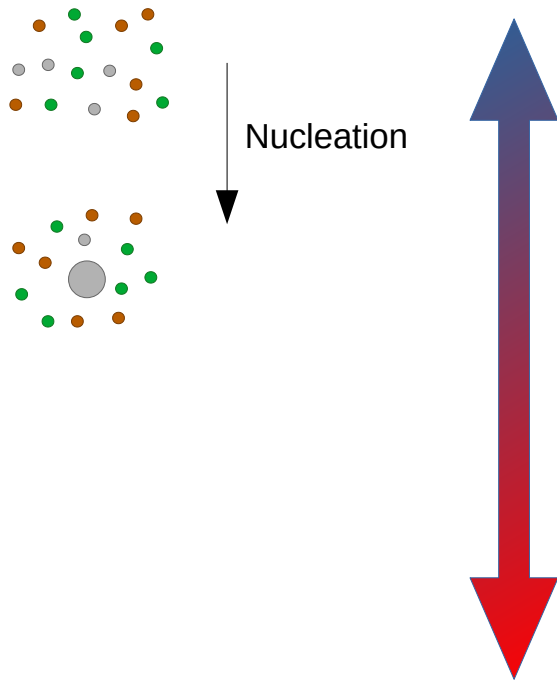
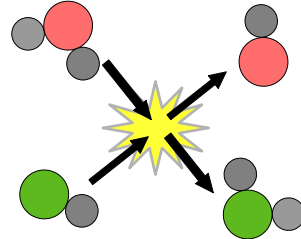
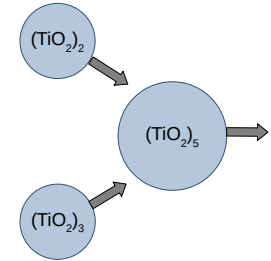


Image altered from Helling (2018)

Kinetic Chemistry



Kinetic nucleation

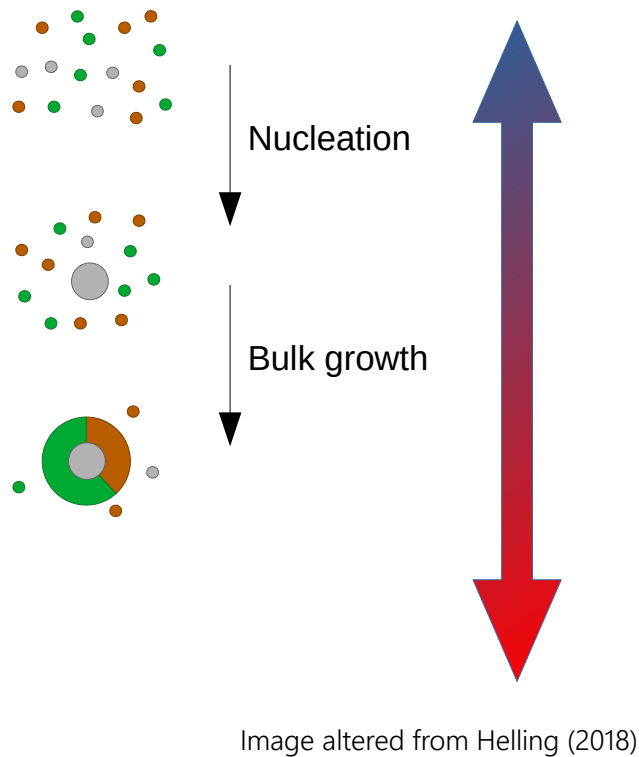


Nucleation:

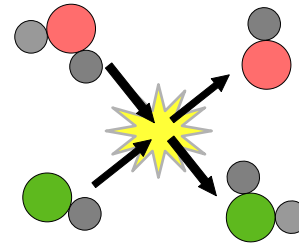
→ Species: $\text{TiO}_2[s]$

→ Maximum size: $(\text{TiO}_2)_{15}$

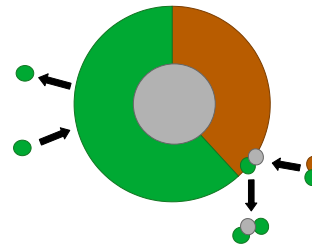
Cloud formation



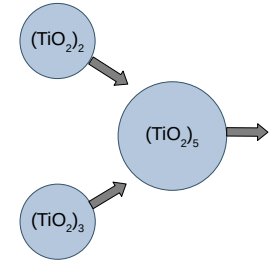
Kinetic Chemistry



Bulk growth



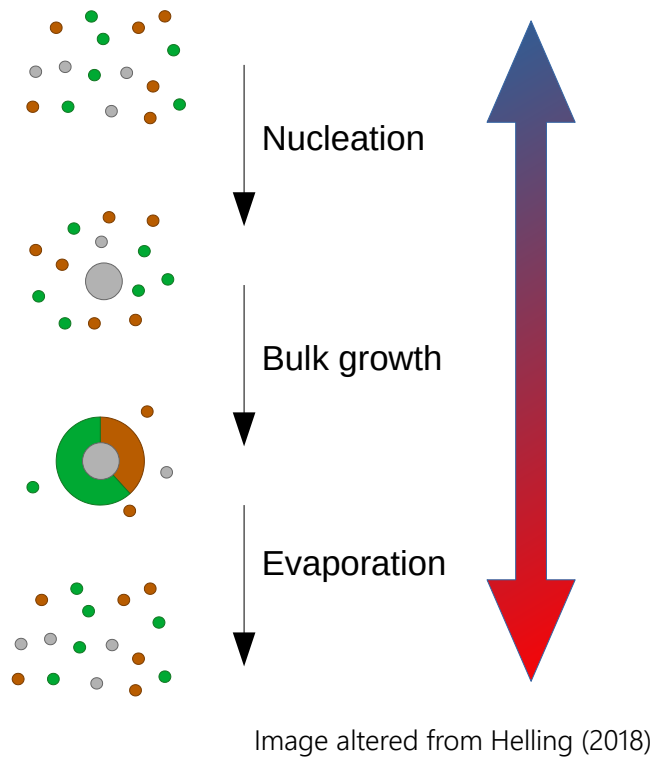
Kinetic nucleation



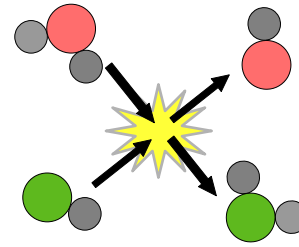
Cloud material

TiO_2	FeO	NaCl
Al_2O_3	Fe_2O_3	KCl
SiO	FeS	MnO
SiO_2	Fe_2SiO_4	Na_2S
Mg_2SiO_4	Fe	MnO
MgSiO_3	CaTiO_3	CaSiO_3

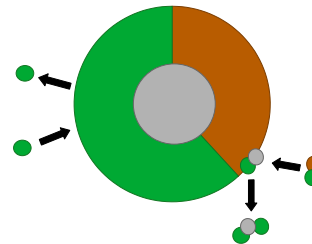
Cloud formation



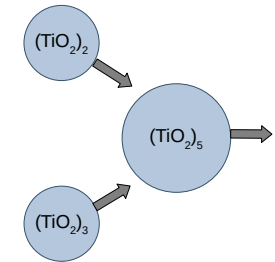
Kinetic Chemistry



Bulk growth



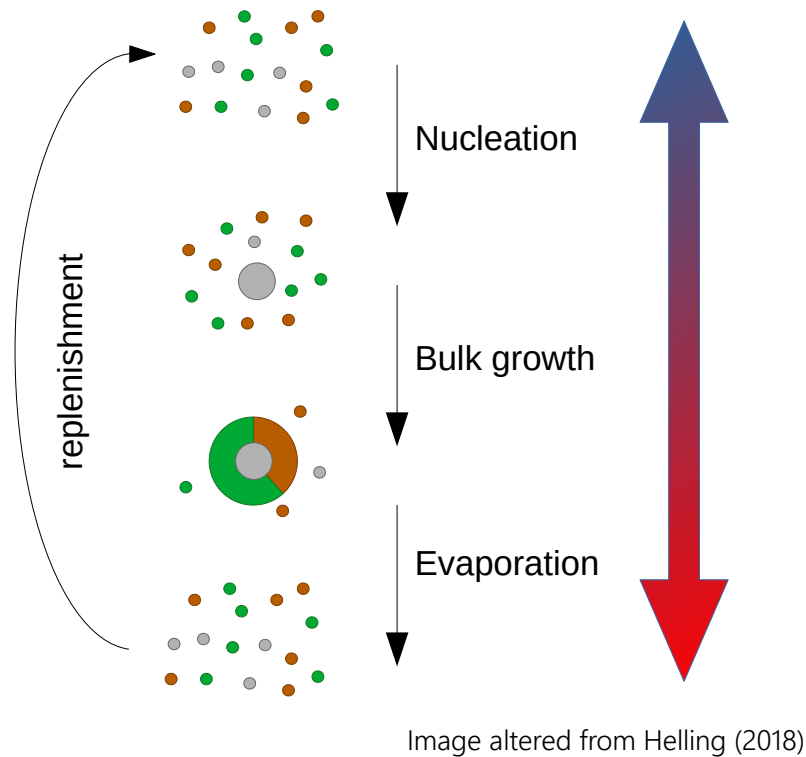
Kinetic nucleation



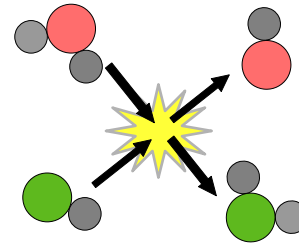
Cloud material

TiO_2	FeO	NaCl
Al_2O_3	Fe_2O_3	KCl
SiO	FeS	MnO
SiO_2	Fe_2SiO_4	Na_2S
Mg_2SiO_4	Fe	MnO
MgSiO_3	CaTiO_3	CaSiO_3

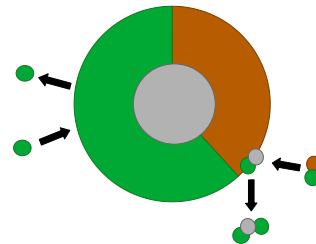
Cloud formation



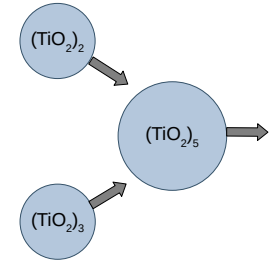
Kinetic Chemistry



Bulk growth



Kinetic nucleation

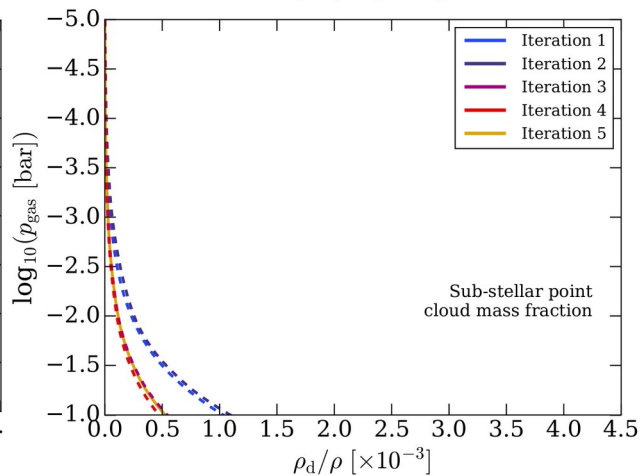
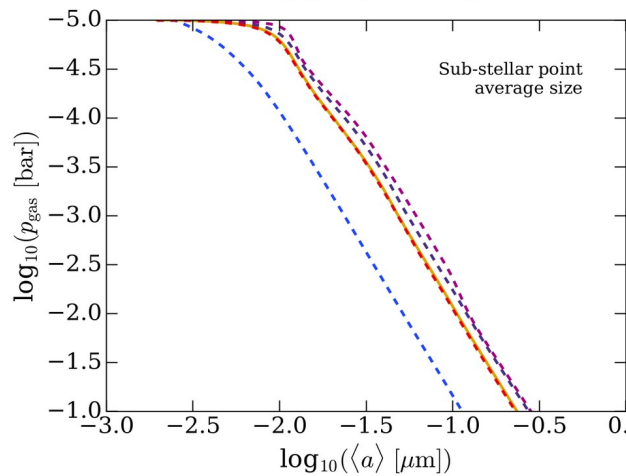
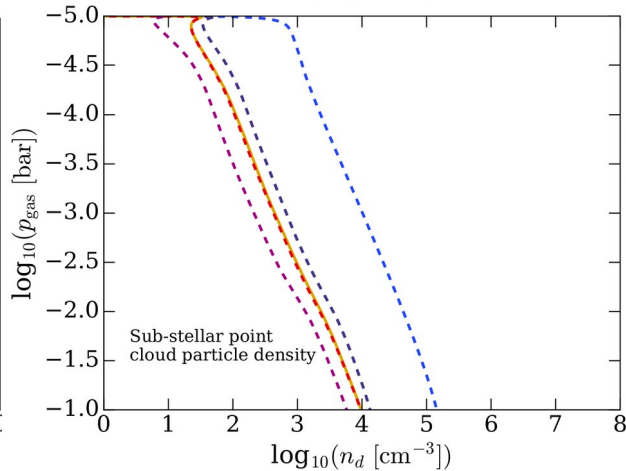
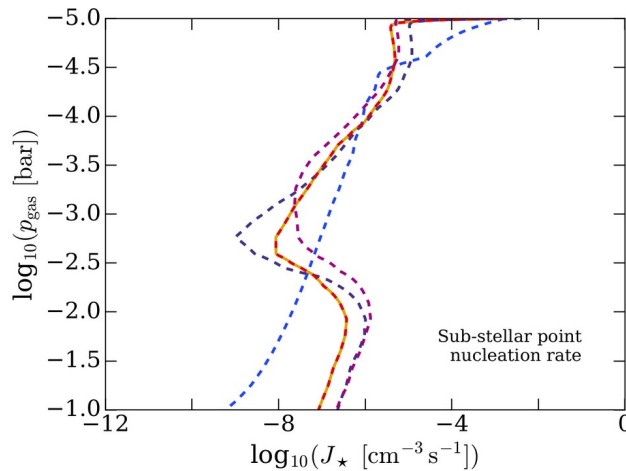
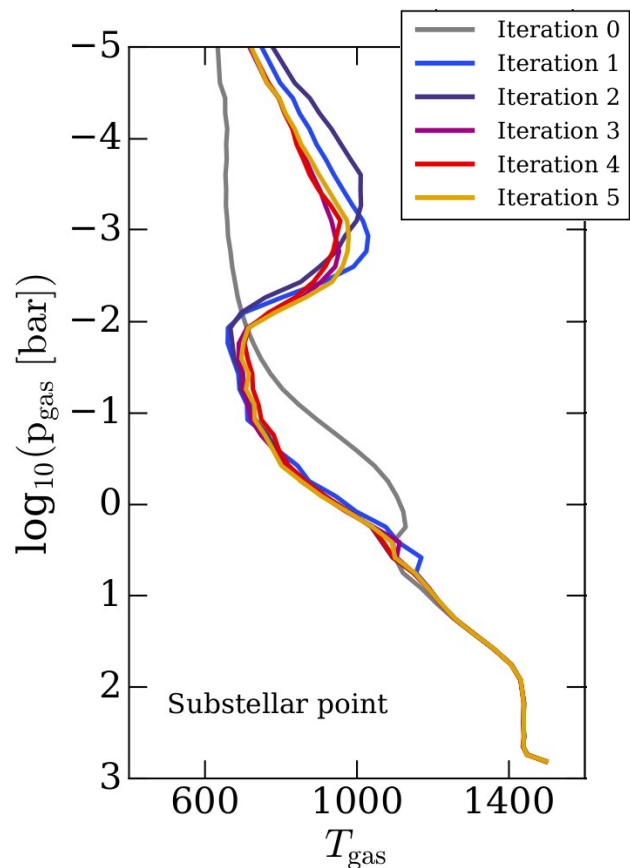


Cloud material

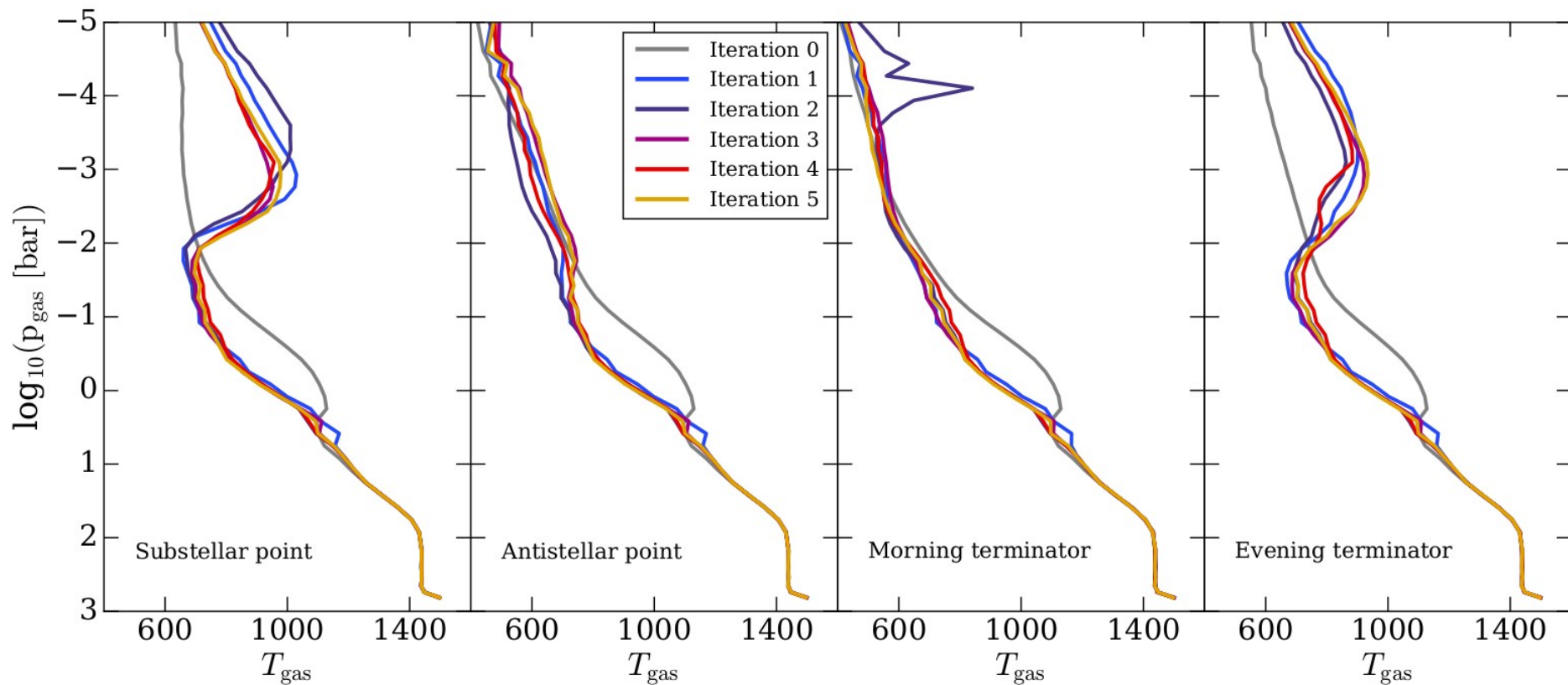
TiO_2	FeO	NaCl
Al_2O_3	Fe_2O_3	KCl
SiO	FeS	MnO
SiO_2	Fe_2SiO_4	Na_2S
Mg_2SiO_4	Fe	MnO
MgSiO_3	CaTiO_3	CaSiO_3

Clouds in 3D

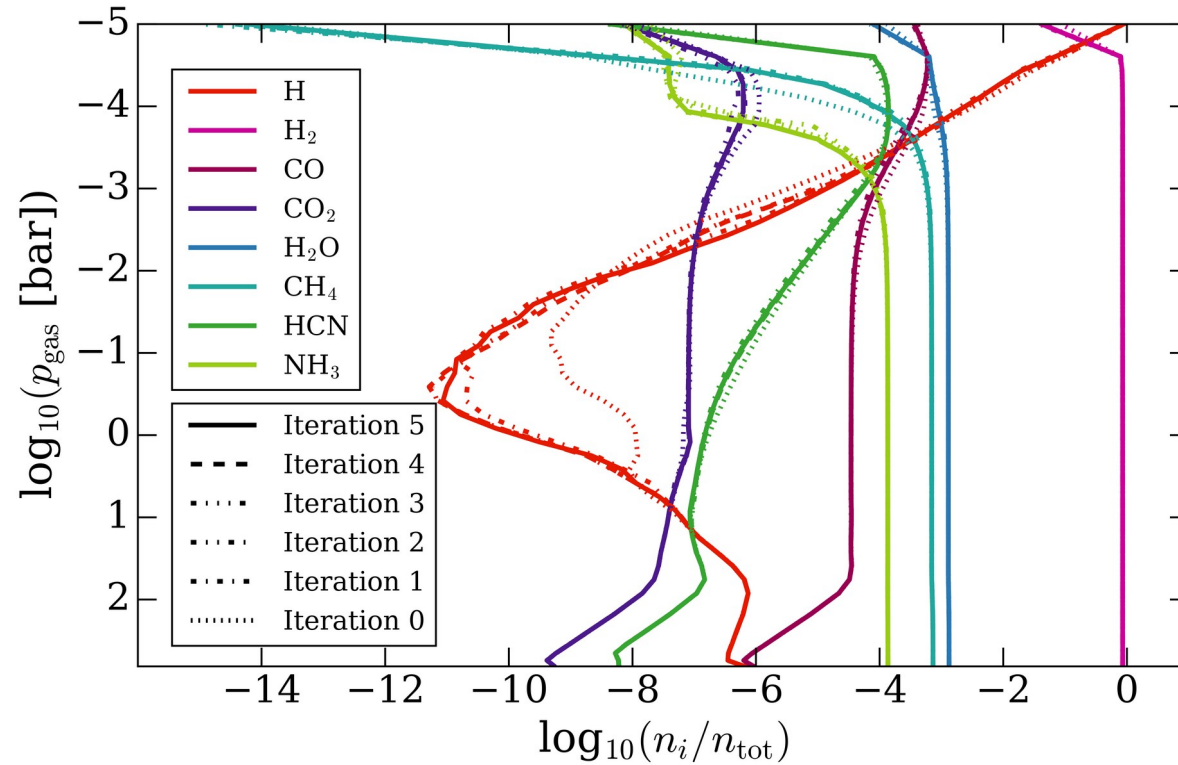
Clouds in 3D



HATS-6b

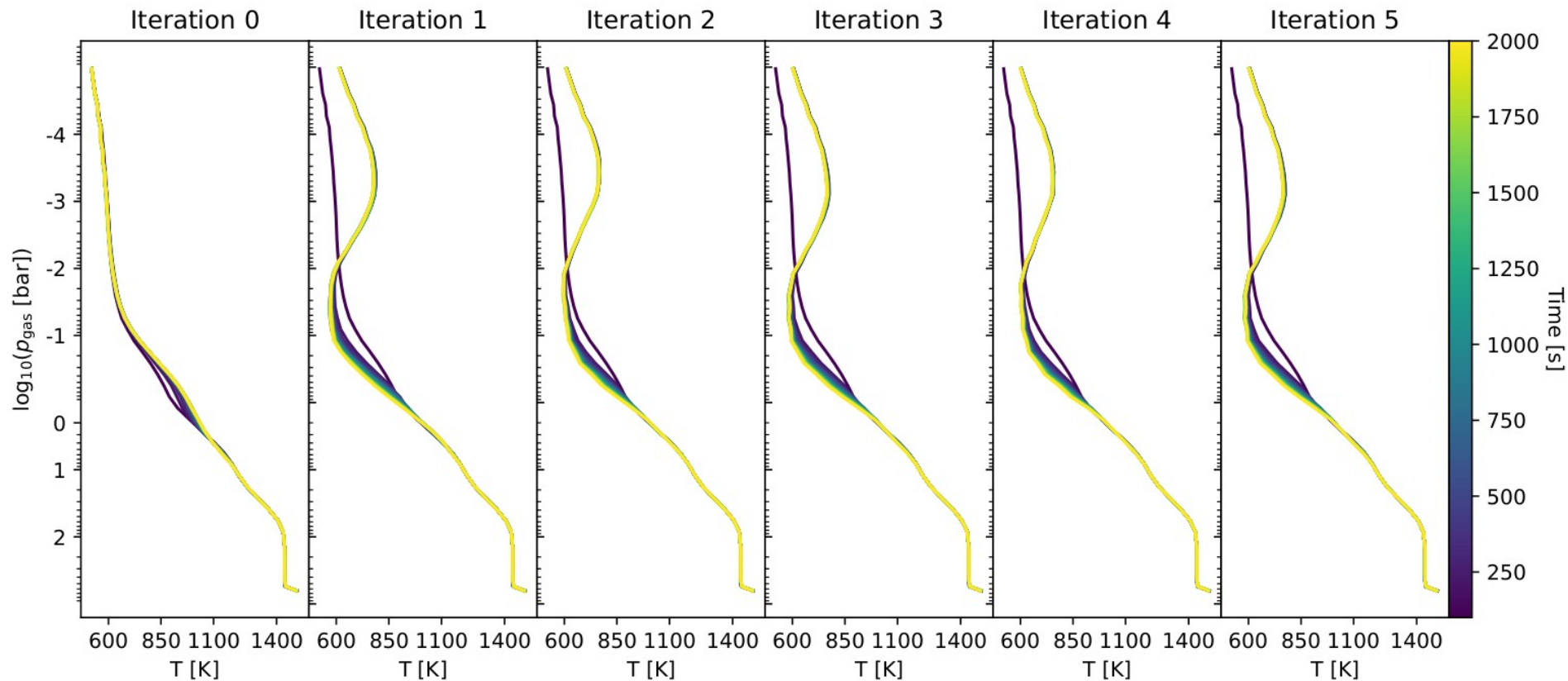


Chemistry

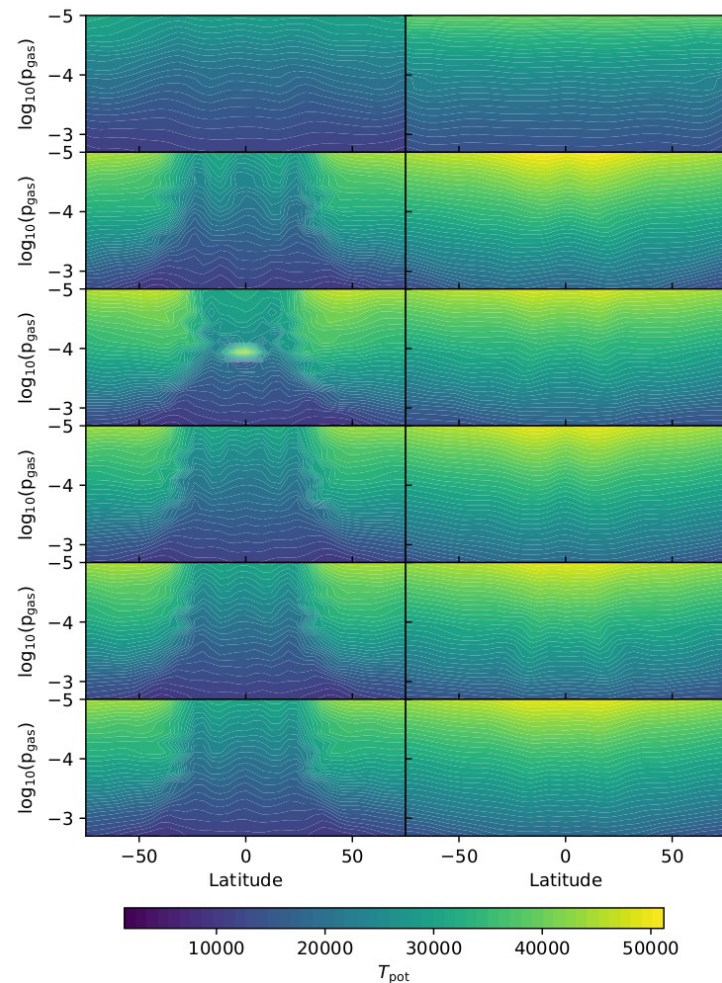
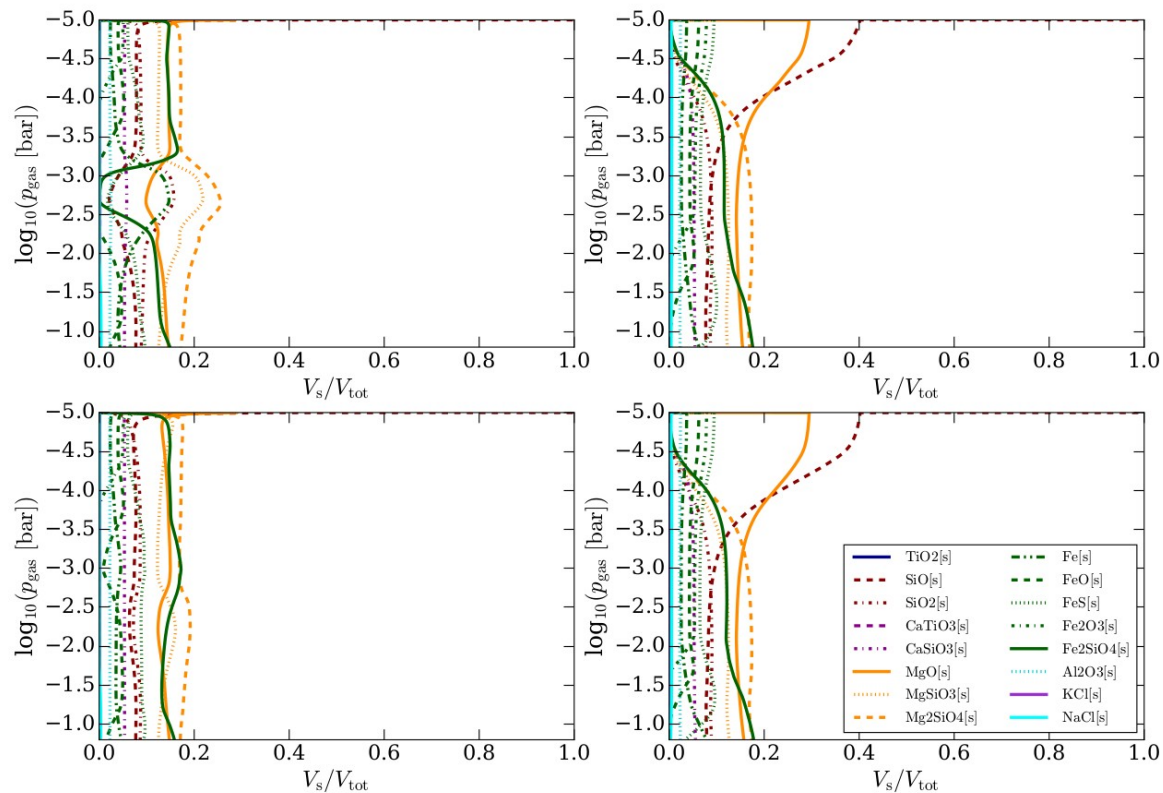


Chemistry

HATS-6b



HATS-6b



Observing HATS-6b

