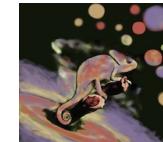


The cloudy climate of HATS-6b

Sven Kiefer

KU Leuven, OEWIWF, 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



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

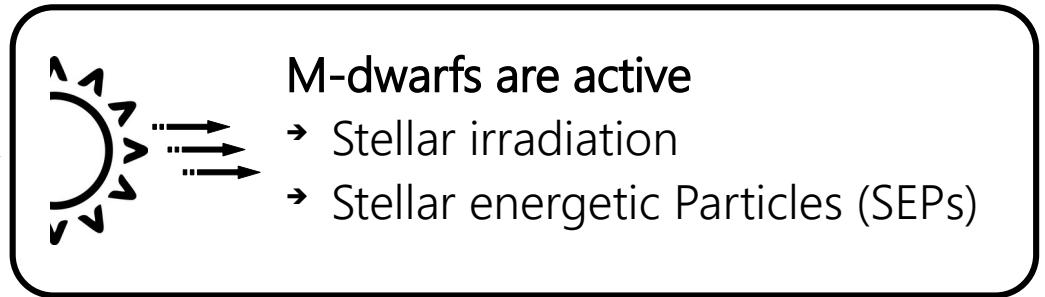
Why HATS-6b?

Why HATS-6b?

HATS-6 b	
<hr/>	
Star:	
 $0.57 M_{\odot}$	
 $0.57 R_{\odot}$	
 $3724 K$	
$[Fe/H]$	0.2
\equiv	M-dwarf
<hr/>	
Planet:	
 $0.319 M_J$	
 $0.998 R_J$	
 $700 K$	
$[Fe/H]$	0.2
\equiv	Warm Saturn

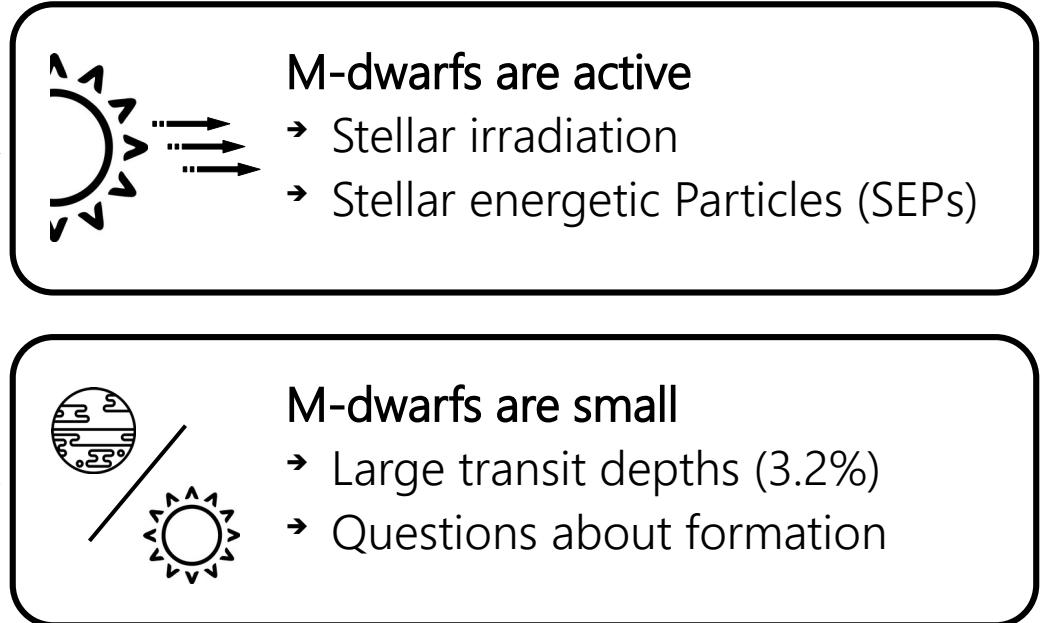
Why HATS-6b?

HATS-6 b	
Star:	
■ Mass: $0.57 M_{\odot}$	
○ Radius: $0.57 R_{\odot}$	
🌡 Temperature: 3724 K	
[Fe/H]: 0.2	
☰ Classification: M-dwarf	
Planet:	
■ Mass: $0.319 M_J$	
○ Radius: $0.998 R_J$	
🌡 Temperature: 700 K	
[Fe/H]: 0.2	
☰ Classification: Warm Saturn	



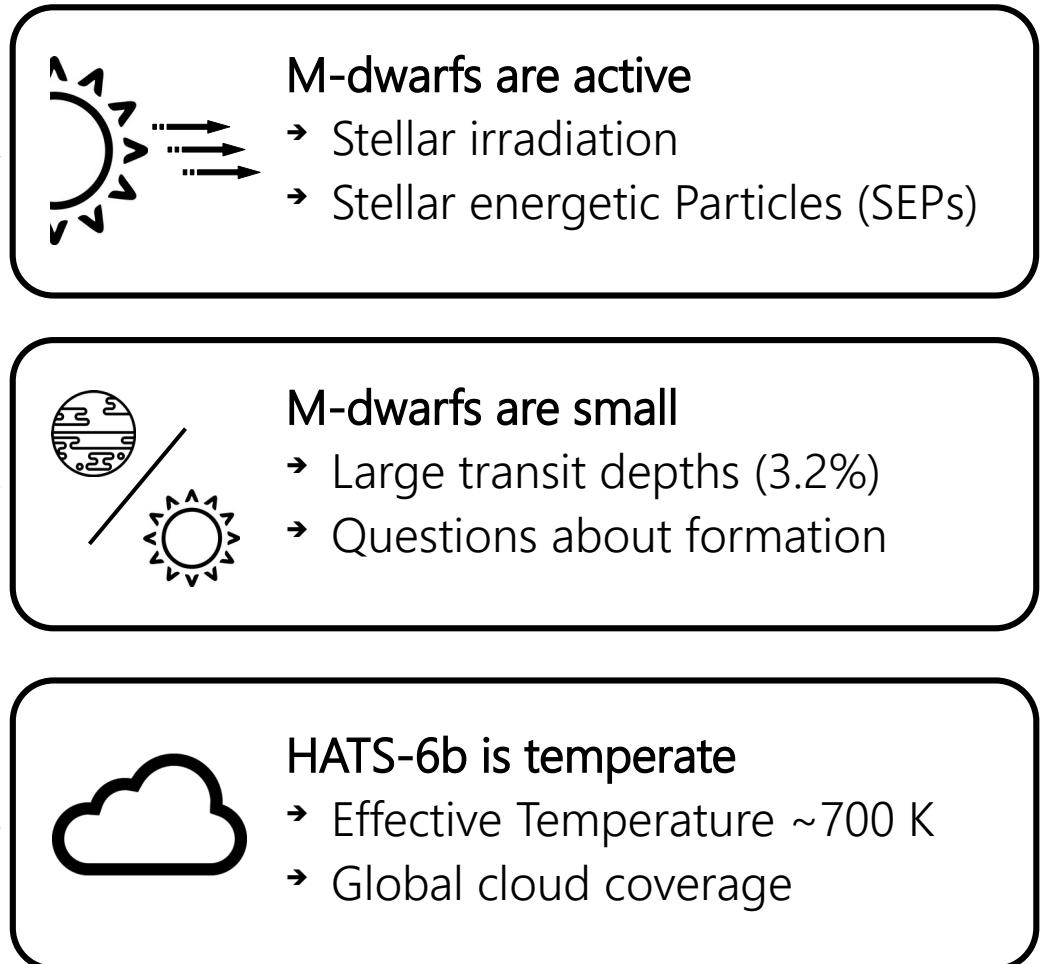
Why HATS-6b?

HATS-6 b	
Star:	
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	3724 K
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	Warm Saturn



Why HATS-6b?

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How we model the atmosphere

How we model the atmosphere

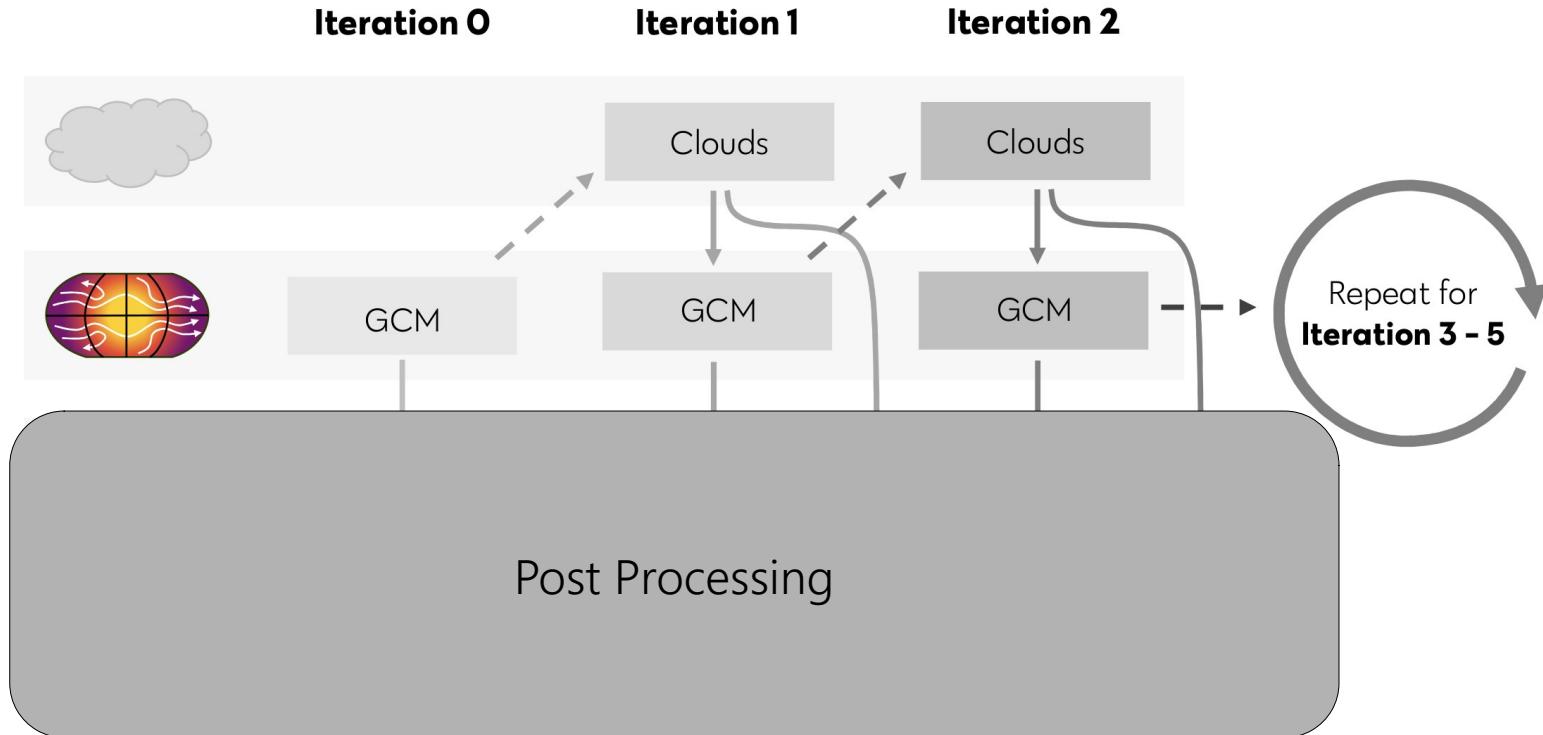
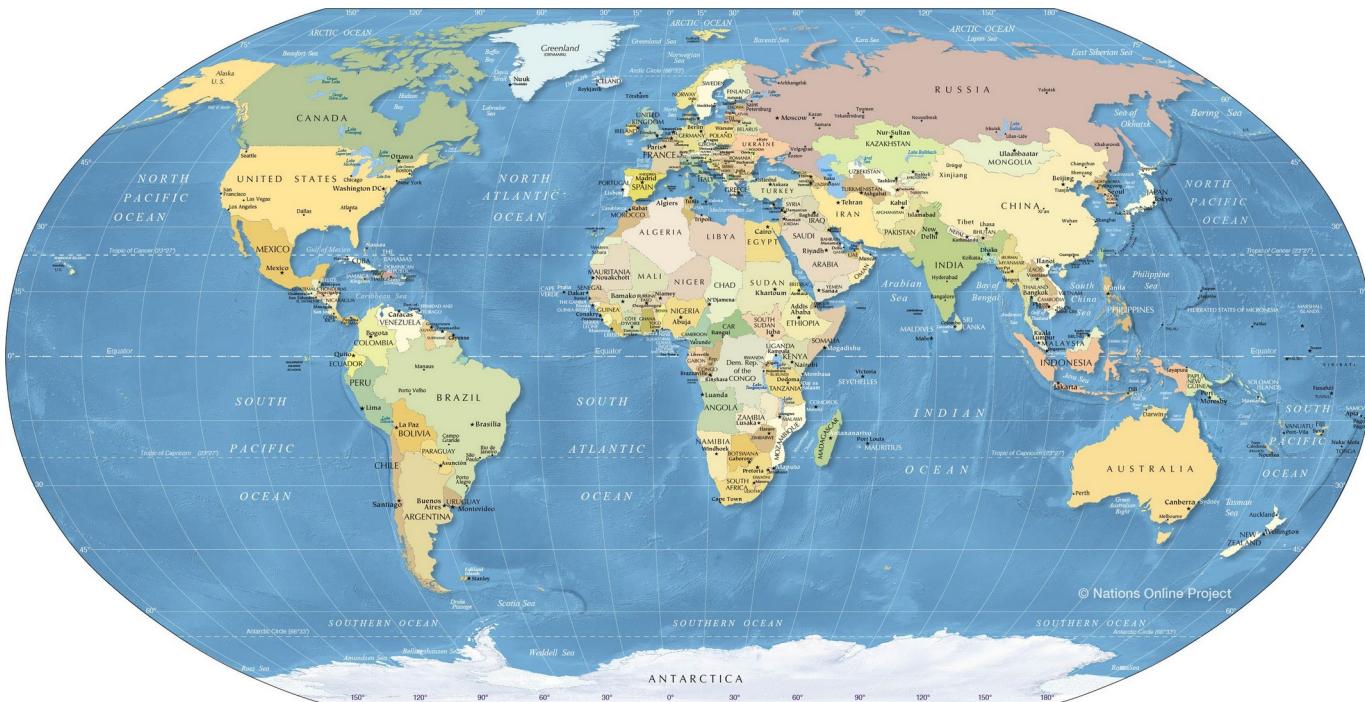
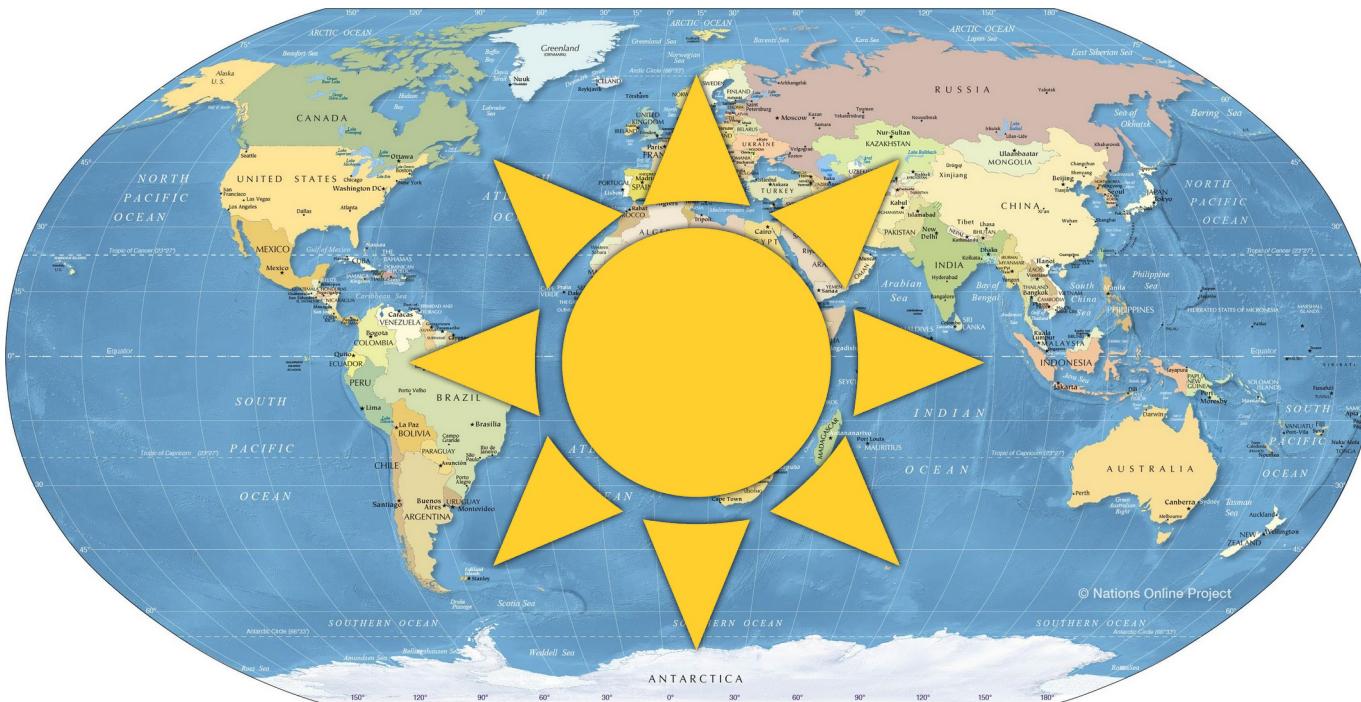


Image credit: N. Bach-Møller

Clouds in 3D



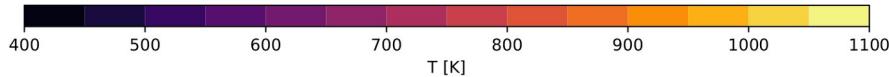
Clouds in 3D



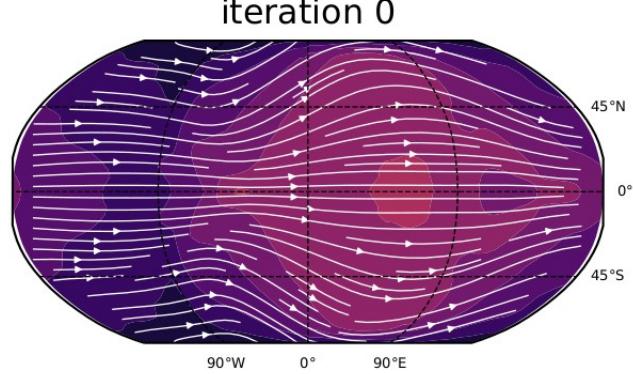
Clouds in 3D



Clouds in 3D



10^{-3} bar



Clouds in 3D – Kinetic cloud formation

Clouds in 3D – Kinetic cloud formation

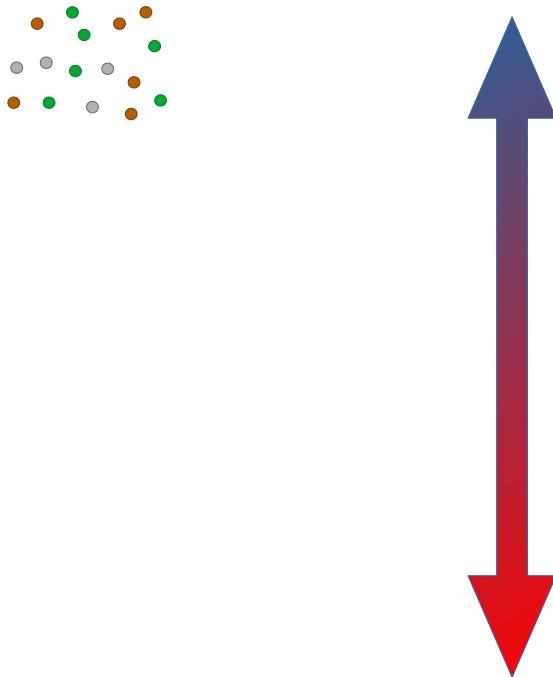


Image altered from Helling (2018)

Clouds in 3D – Kinetic cloud formation

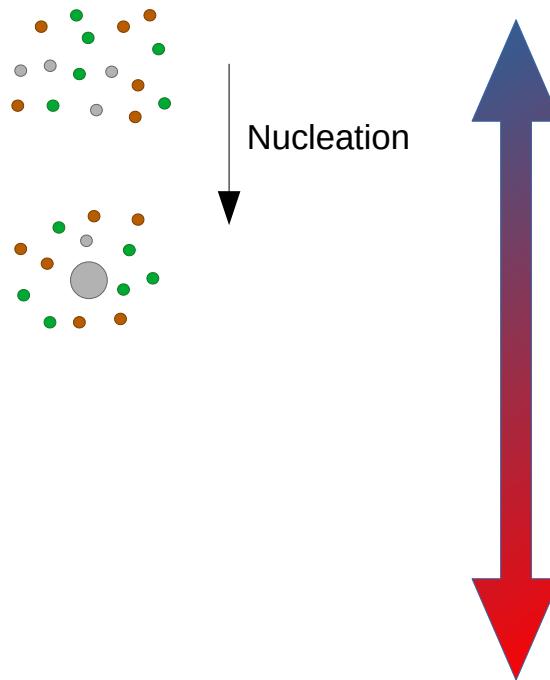


Image altered from Helling (2018)

Clouds in 3D – Kinetic cloud formation

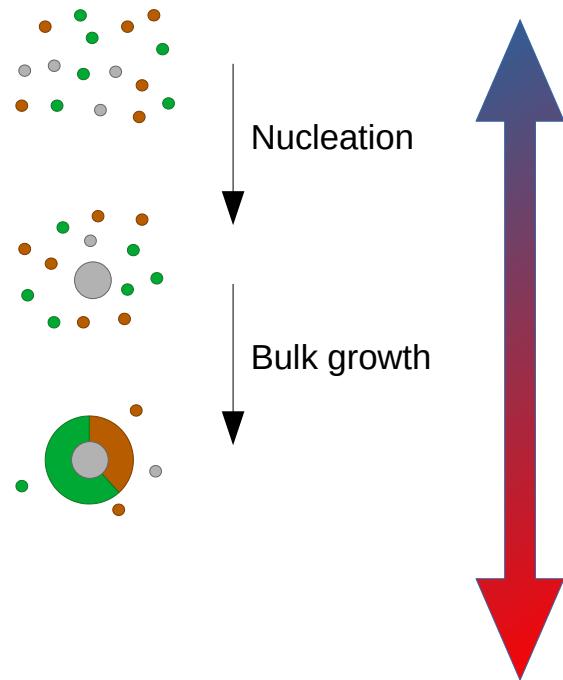


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Clouds in 3D – Kinetic cloud formation

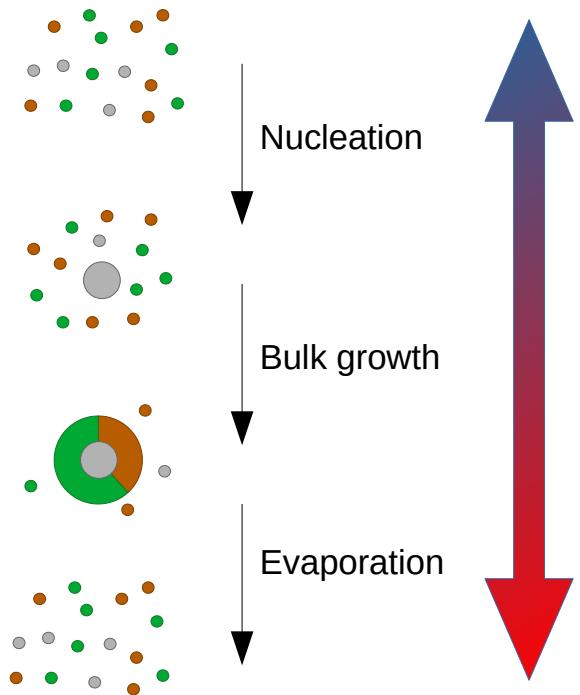


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Clouds in 3D – Kinetic cloud formation

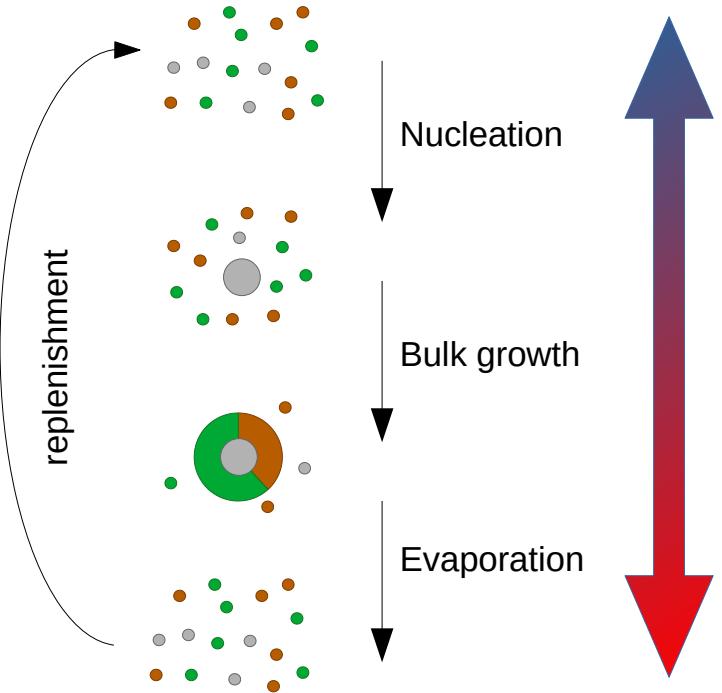


Image altered from Helling (2018)

Clouds in 3D – Kinetic cloud formation

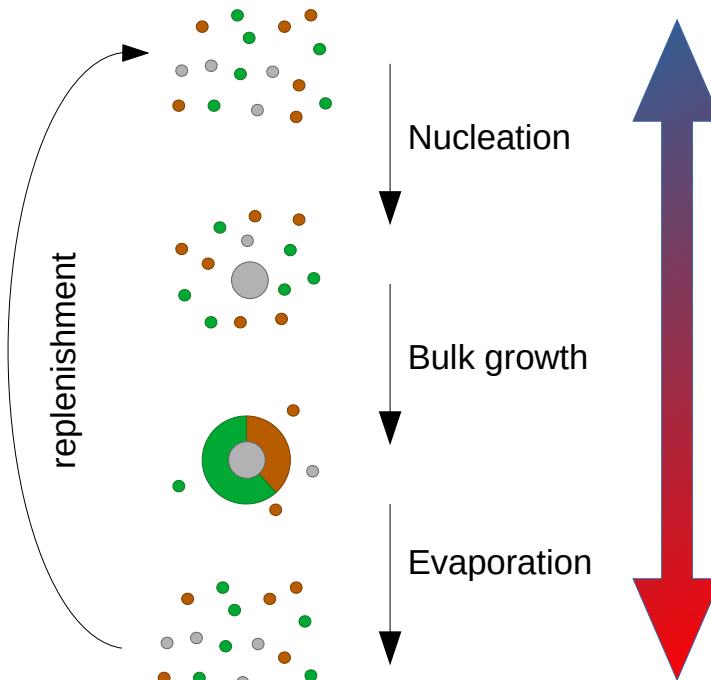
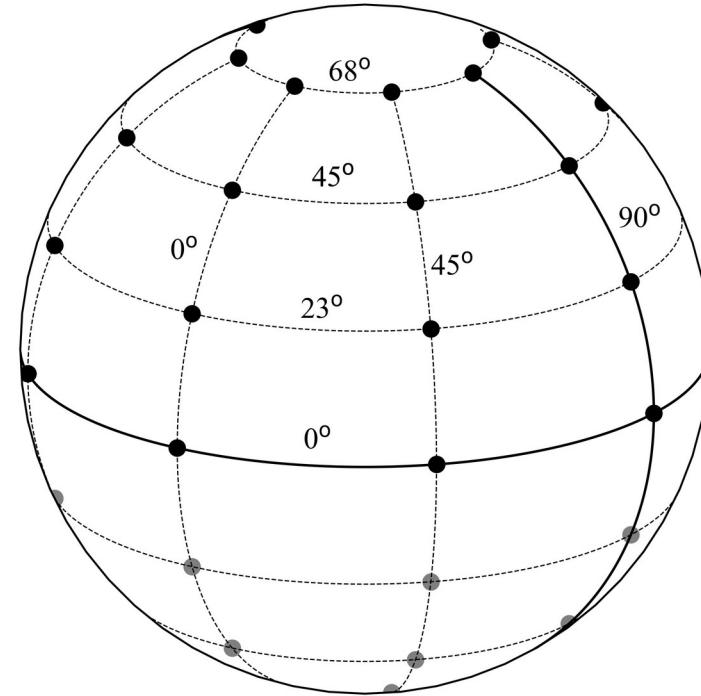
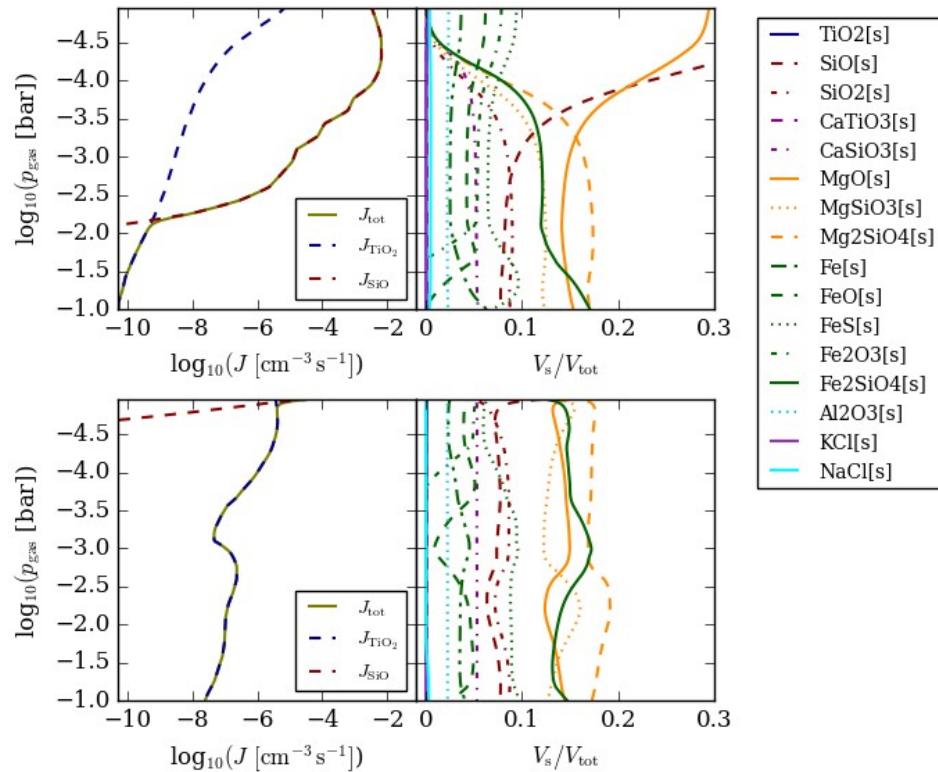


Image altered from Helling (2018)

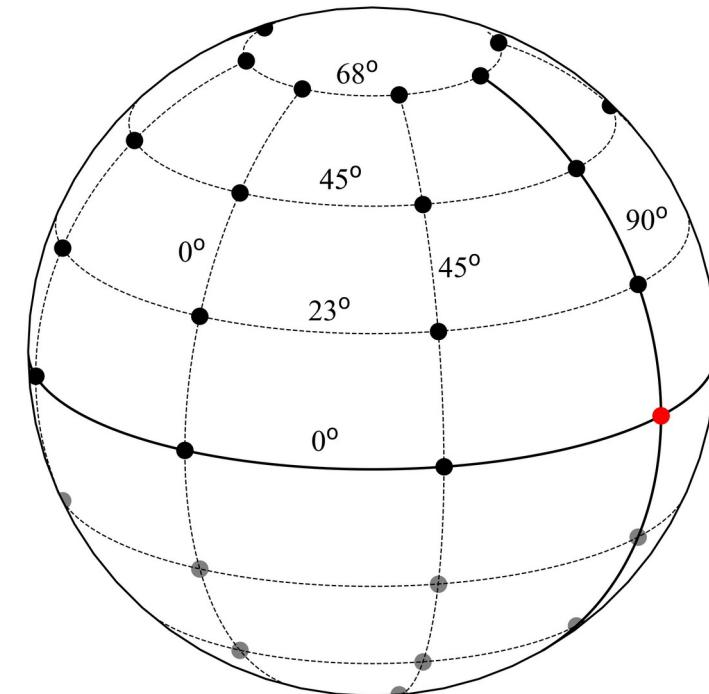


Clouds in 3D – Kinetic cloud formation

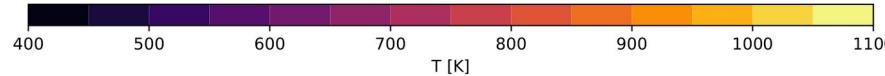
Morning



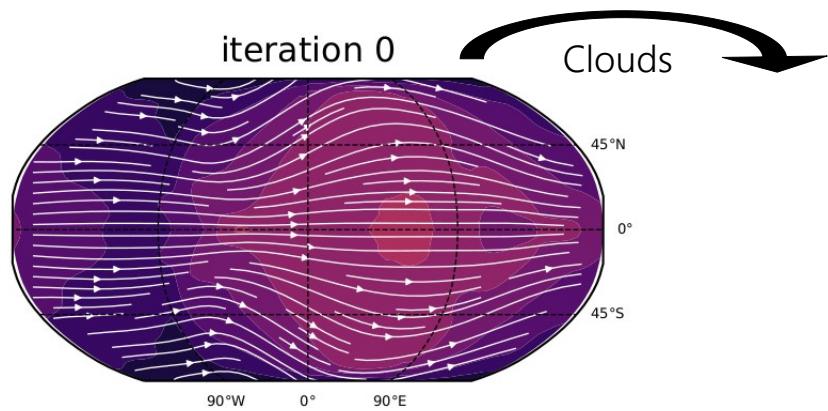
Evening



Clouds in 3D

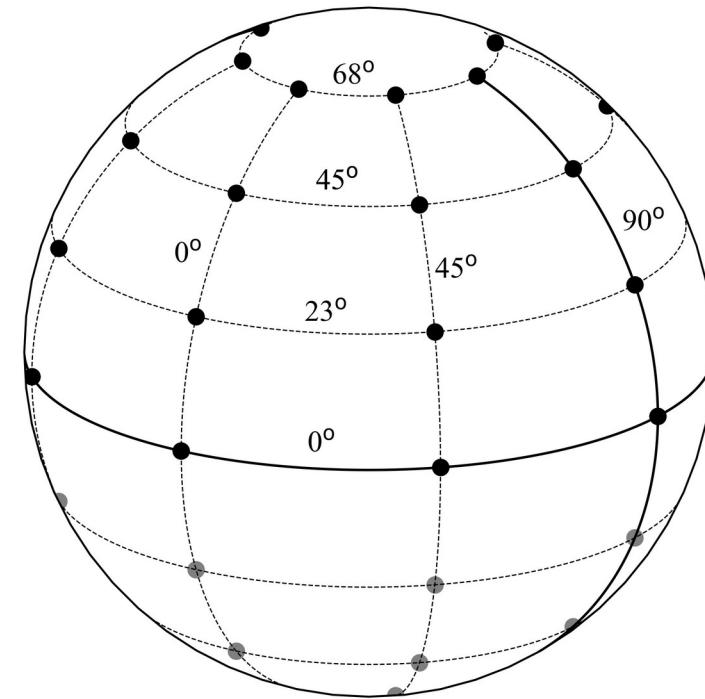


10^{-3} bar

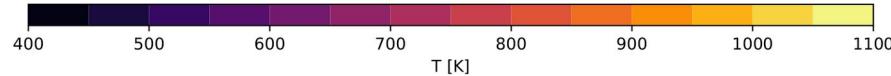


iteration 0

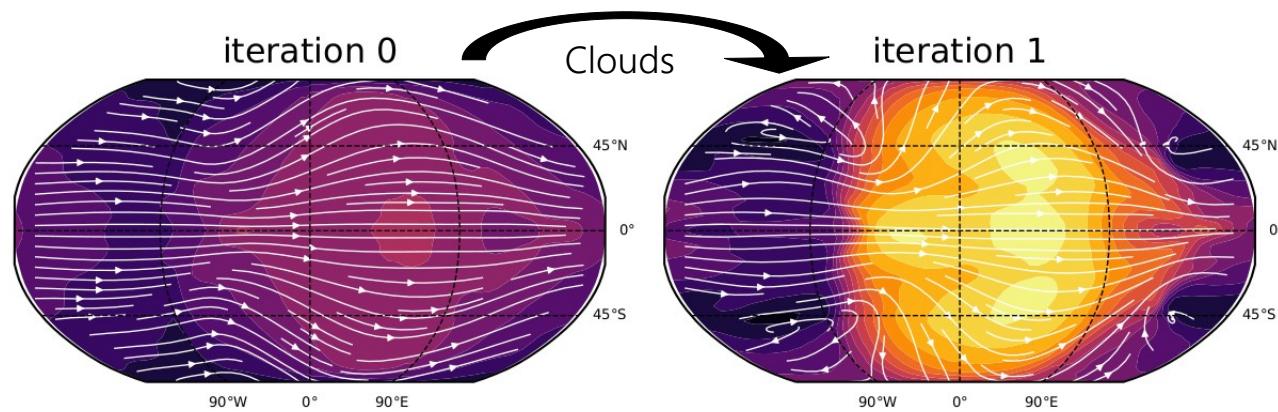
Clouds



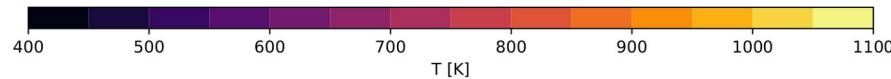
Clouds in 3D



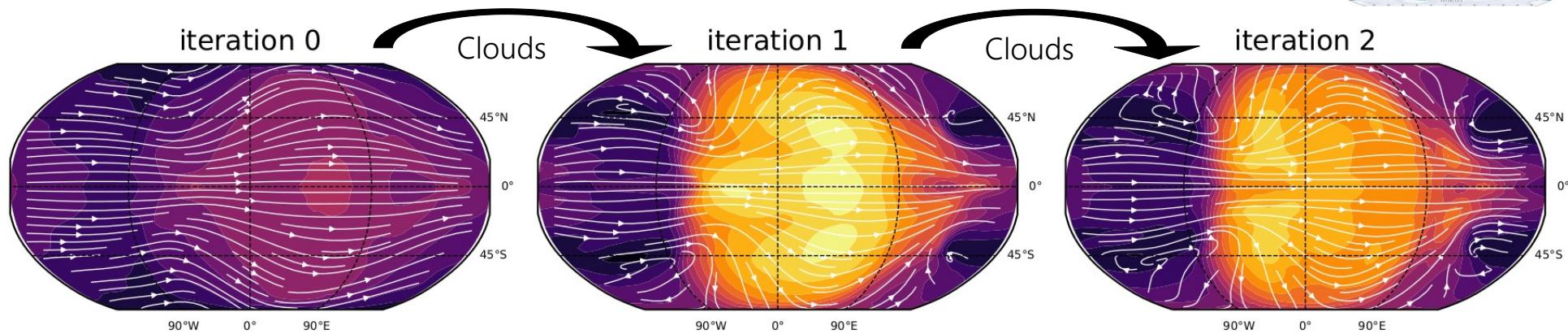
10^{-3} bar



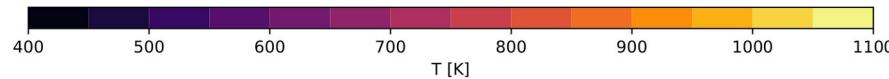
Clouds in 3D



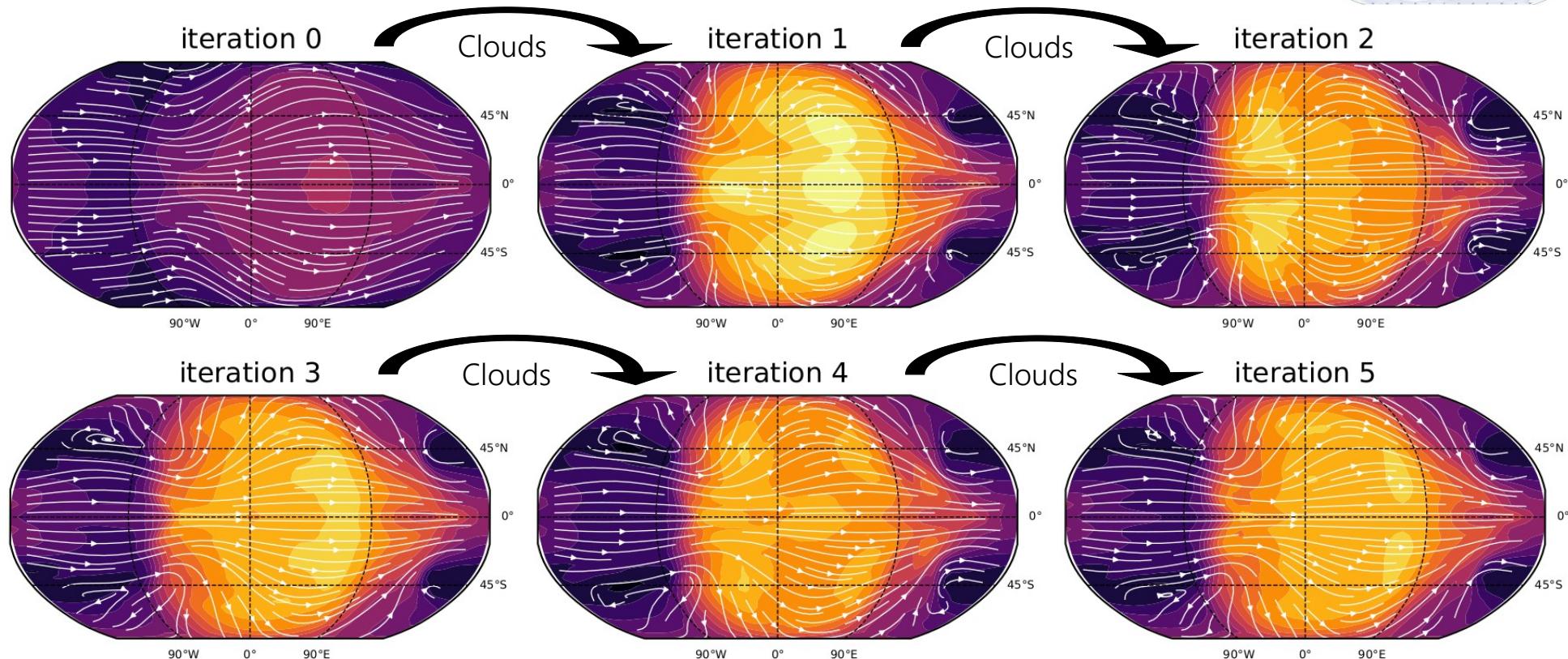
10^{-3} bar



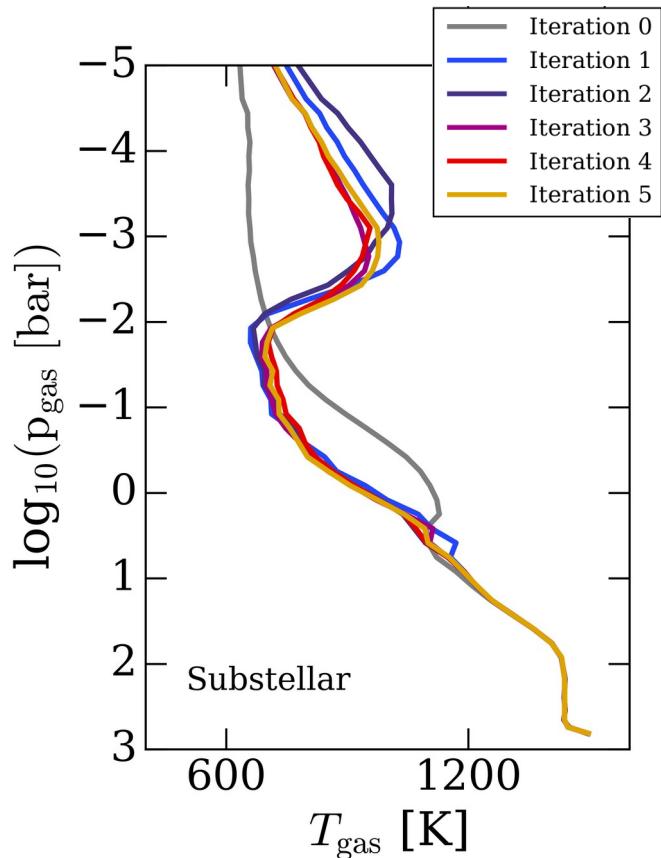
Clouds in 3D



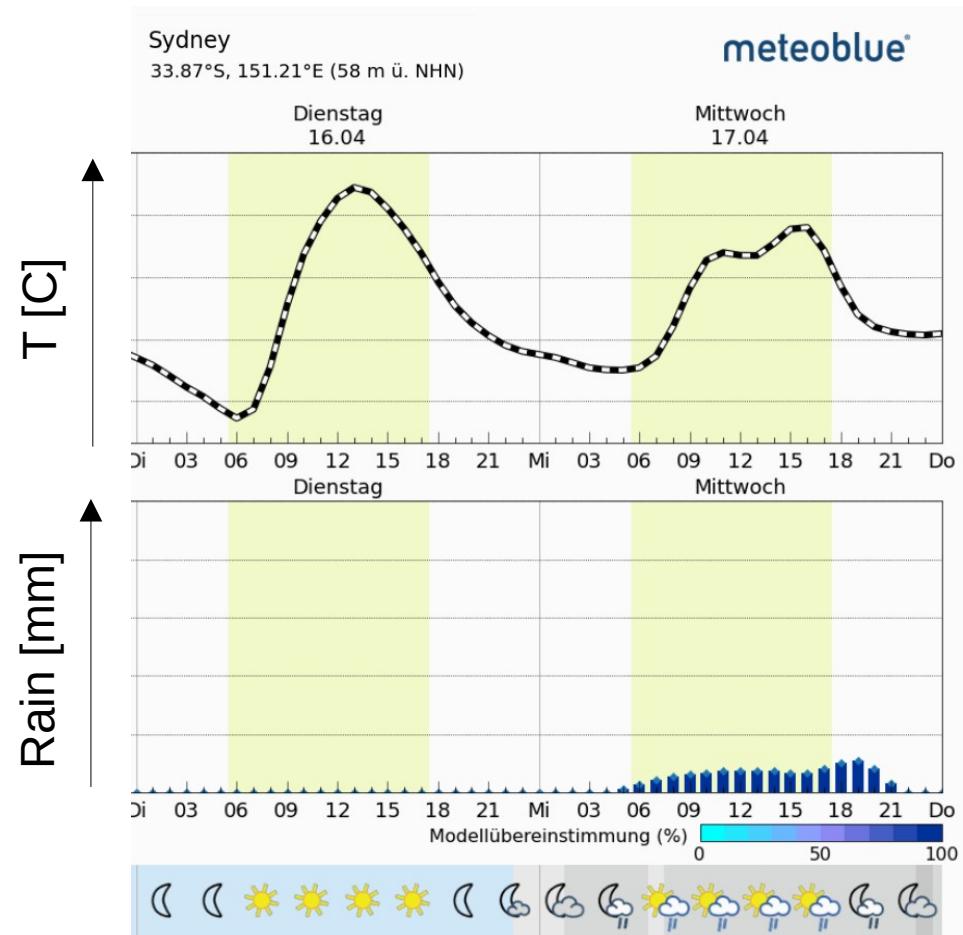
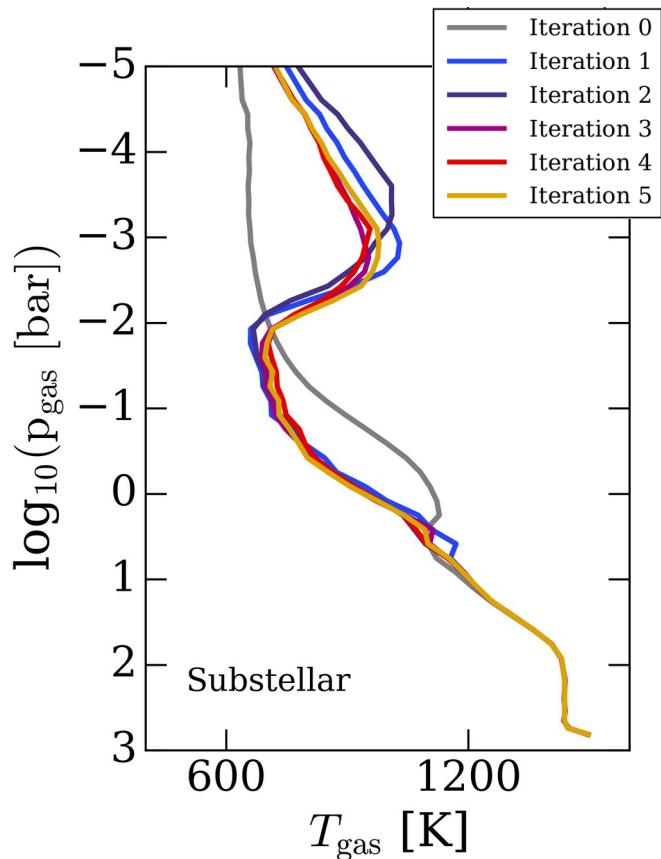
10^{-3} bar



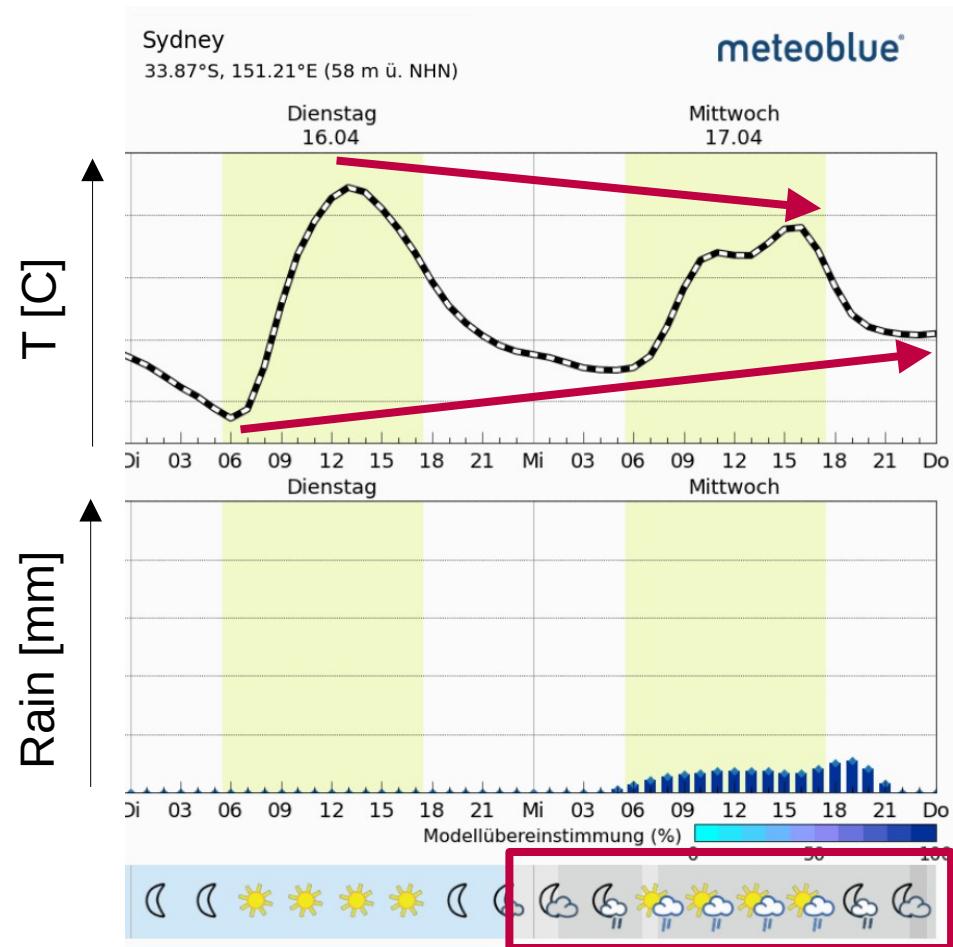
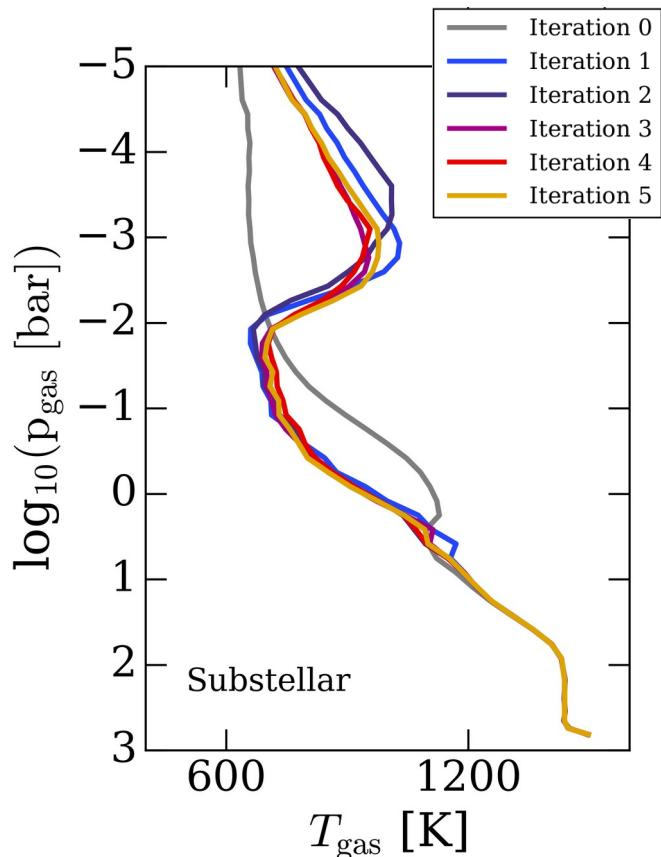
Clouds in 3D



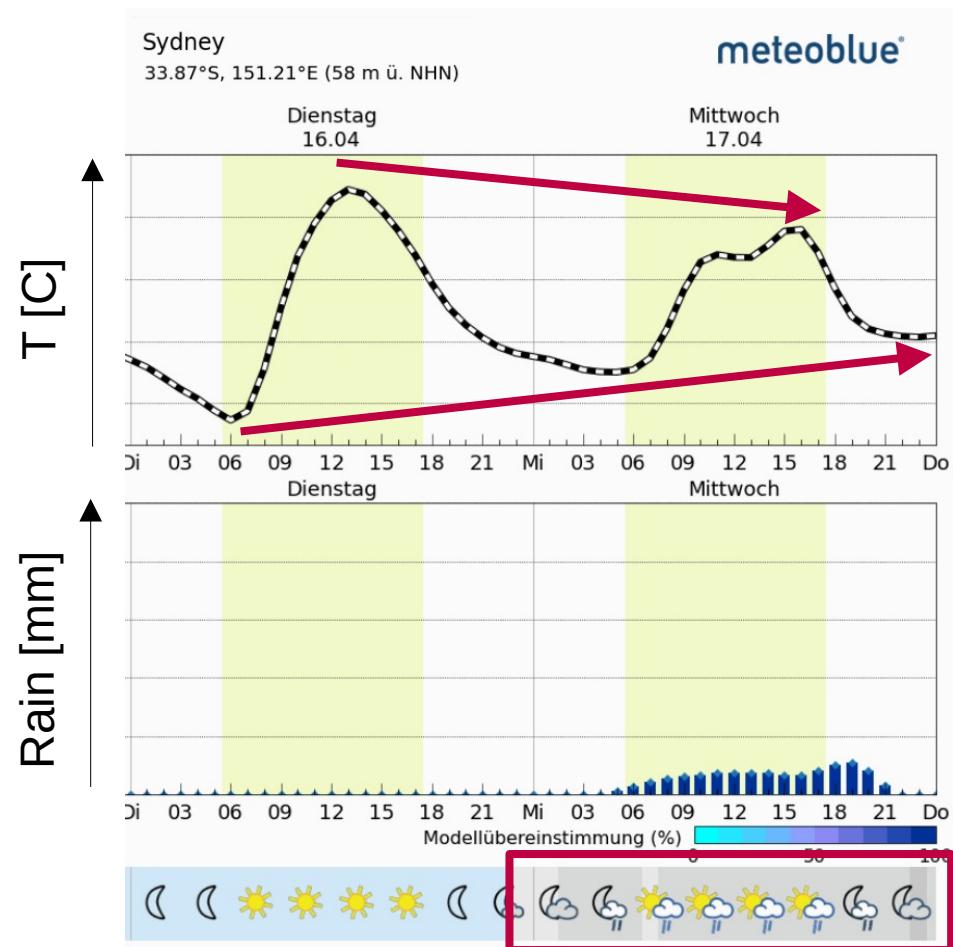
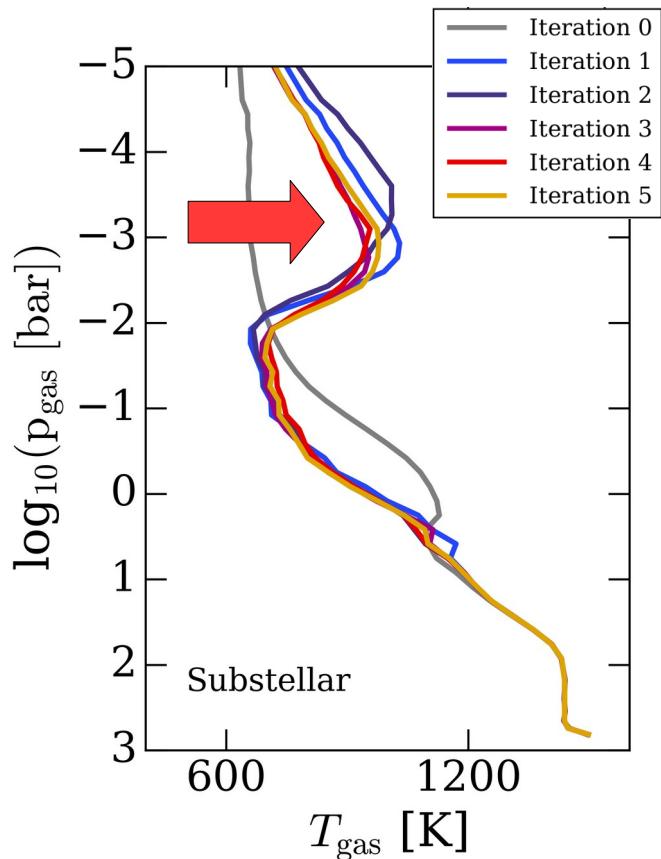
Clouds in 3D



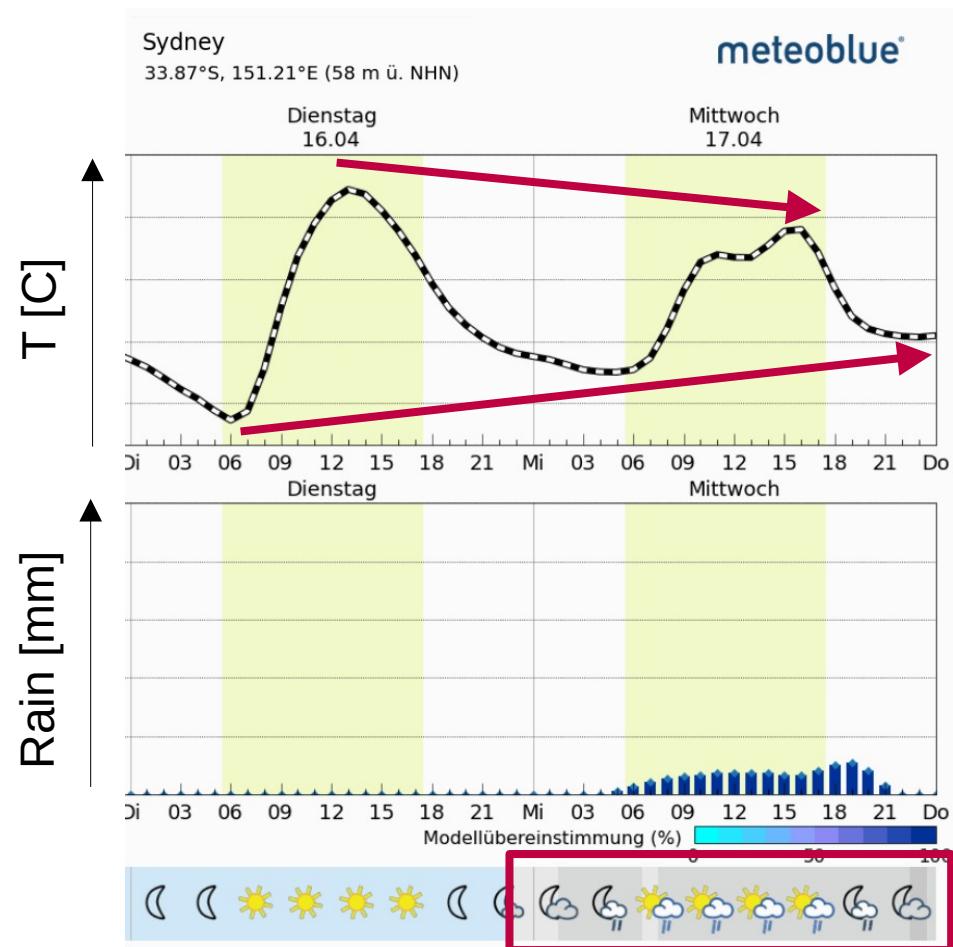
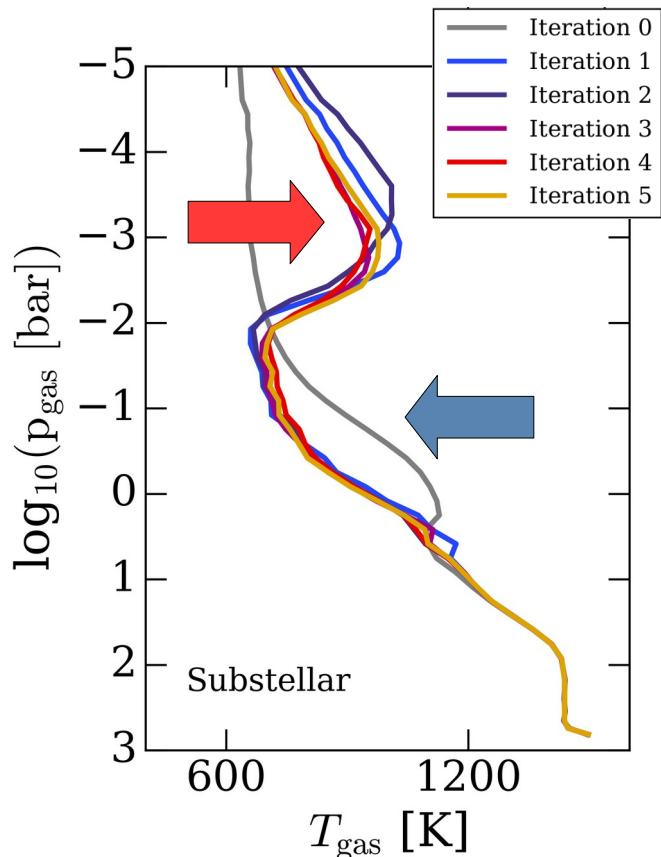
Clouds in 3D



Clouds in 3D



Clouds in 3D



How we model the atmosphere

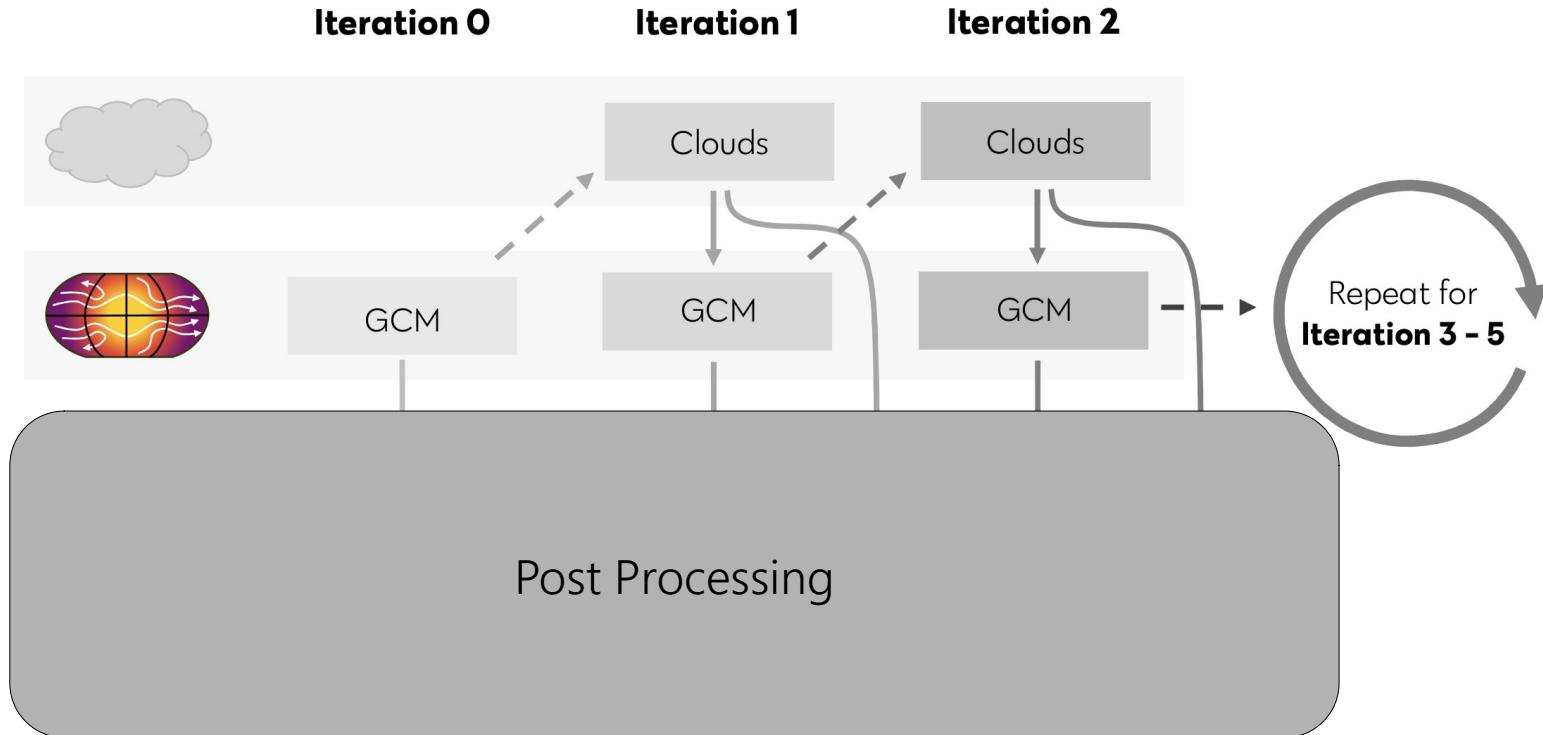


Image credit: N. Bach-Møller

How we model the atmosphere

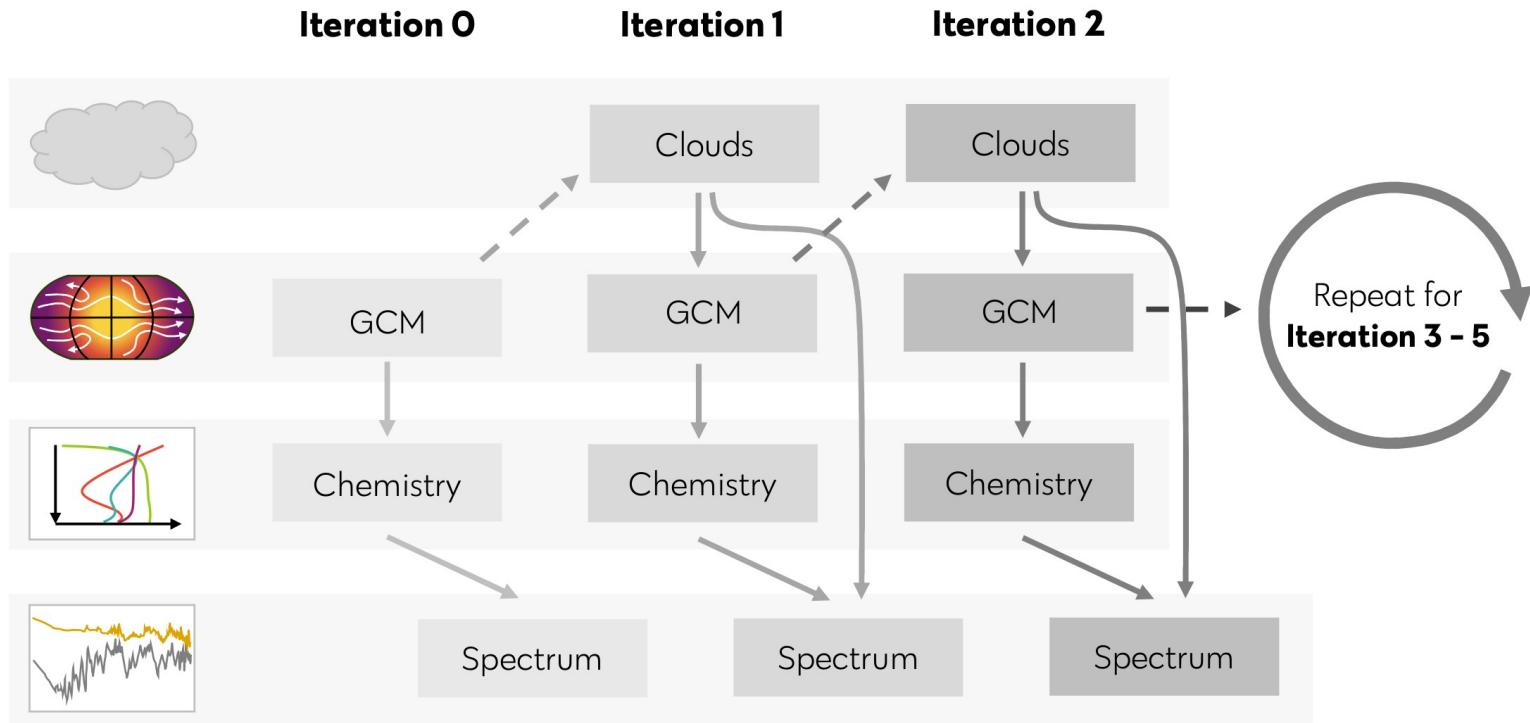
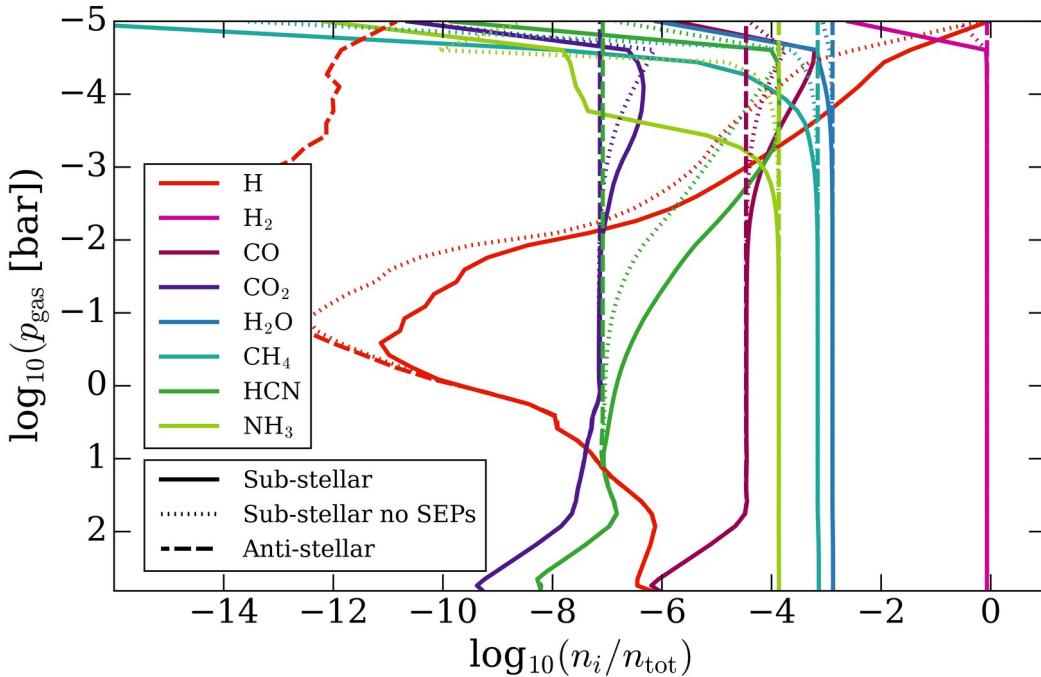
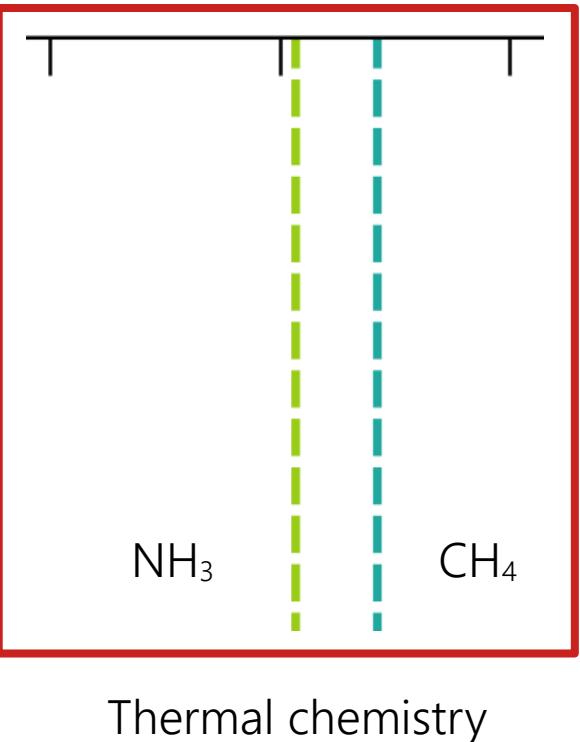
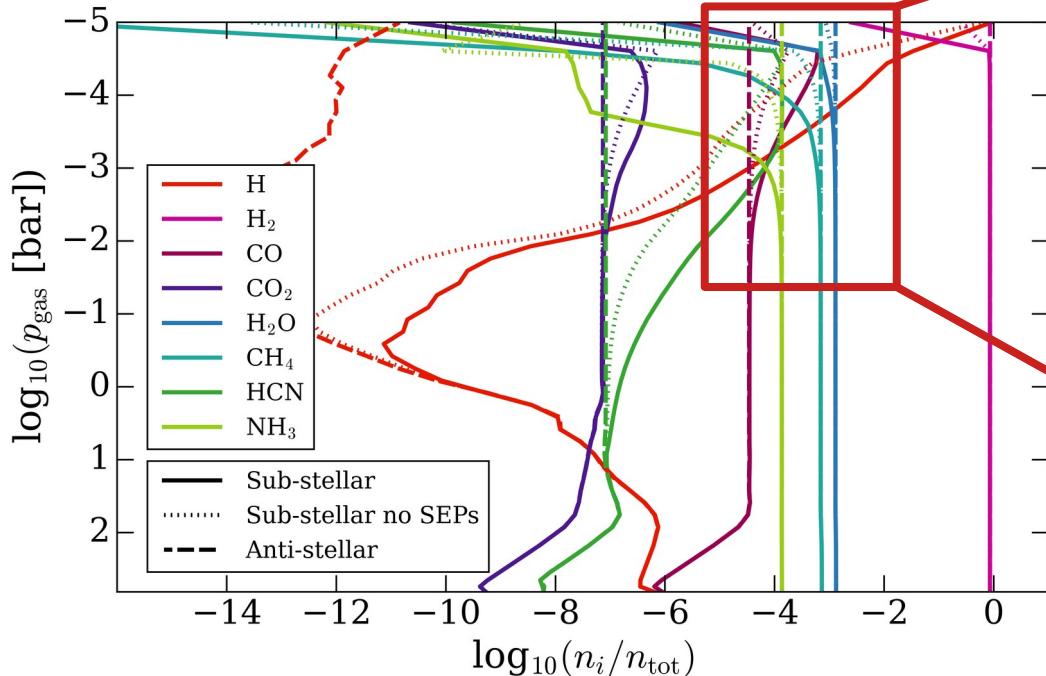


Image credit: N. Bach-Møller

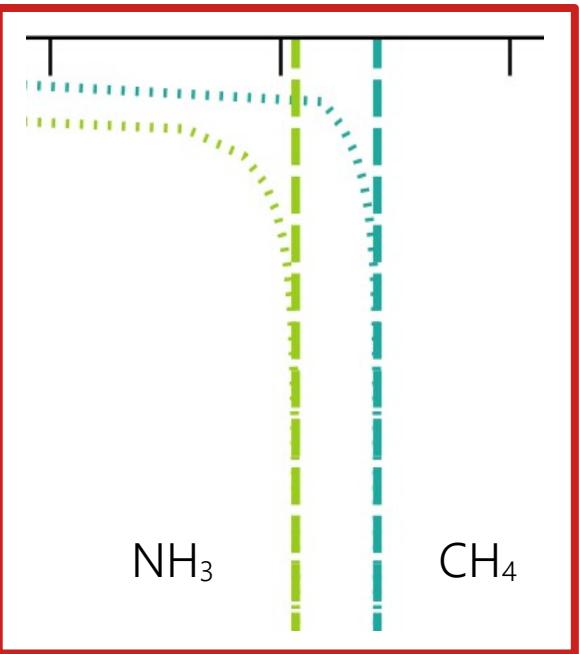
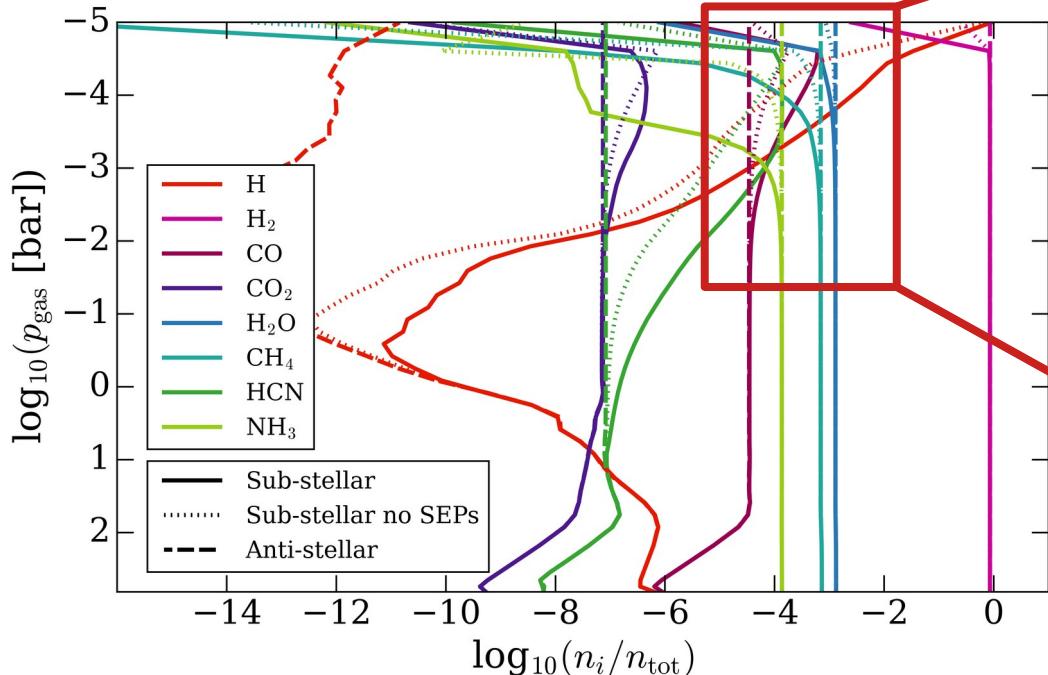
Kinetic gas-phase chemistry



Kinetic gas-phase chemistry

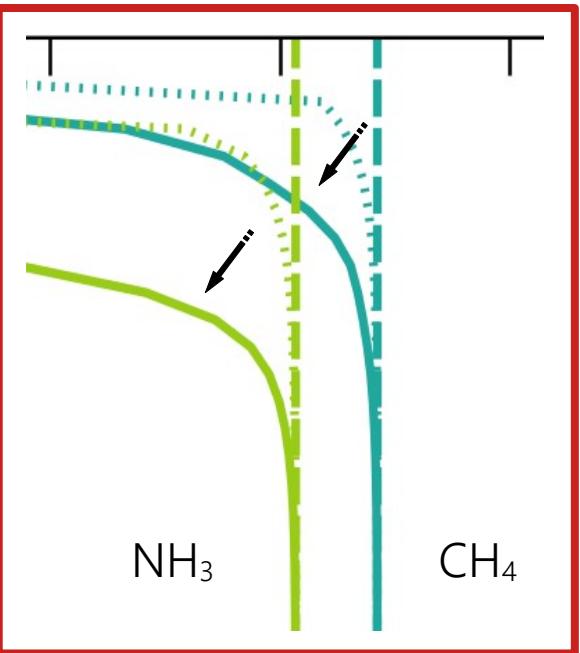
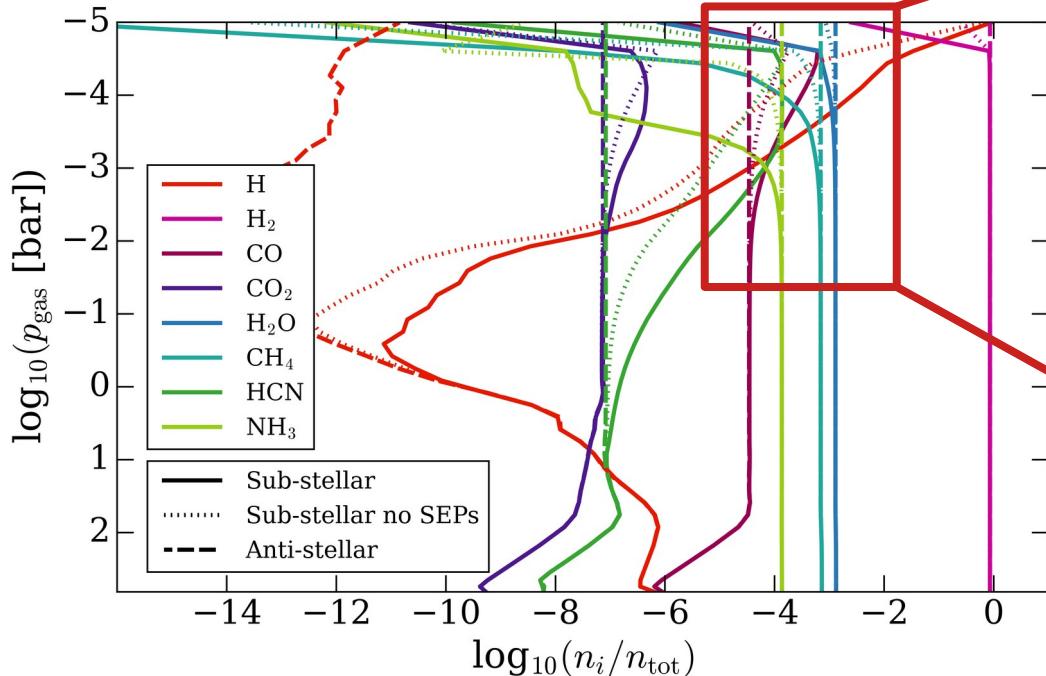


Kinetic gas-phase chemistry



Thermal chemistry
+ XUV photo-chemistry

Kinetic gas-phase chemistry

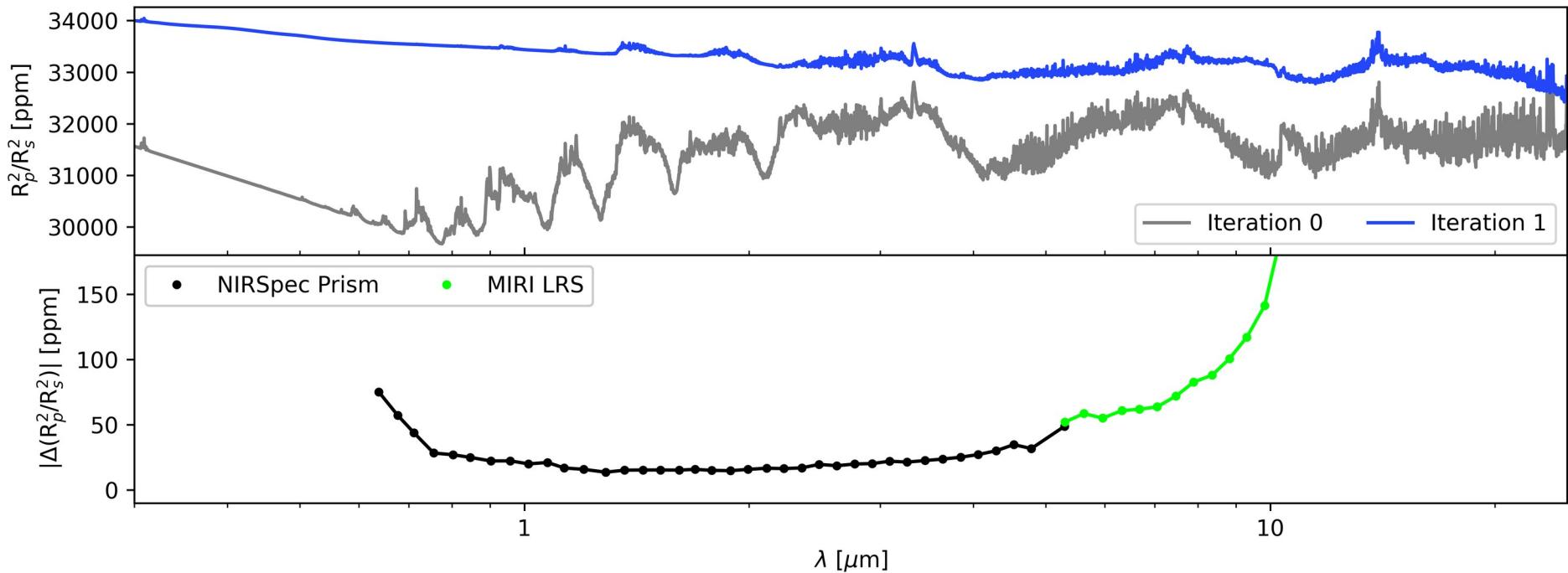


Thermal chemistry
+ XUV photo-chemistry
+ Stellar energetic particles

What can we observe?

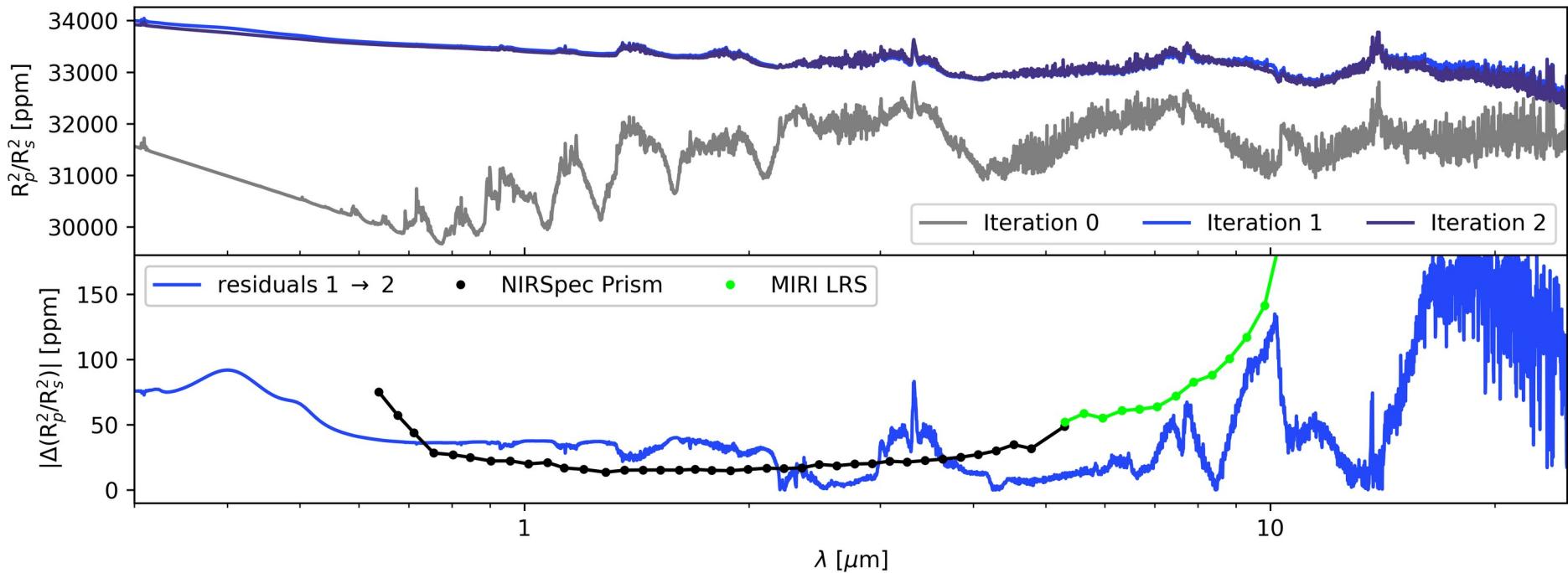


Is it observable?



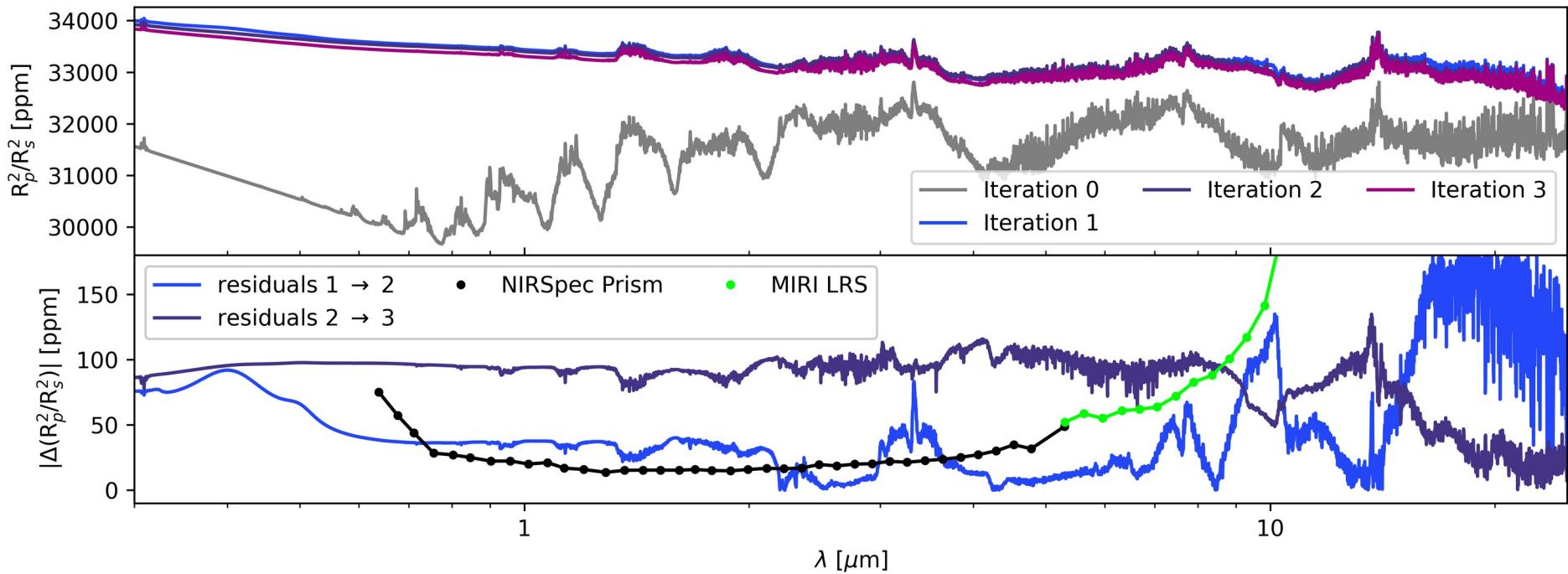


Is it observable?



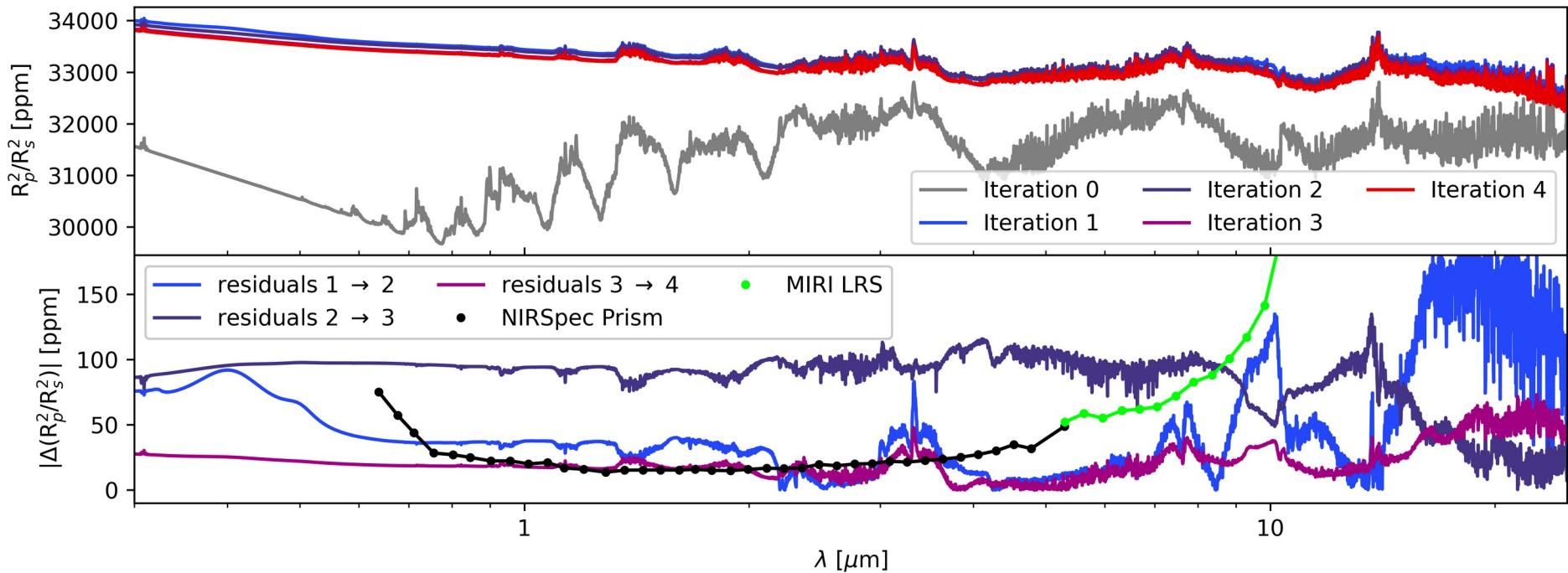


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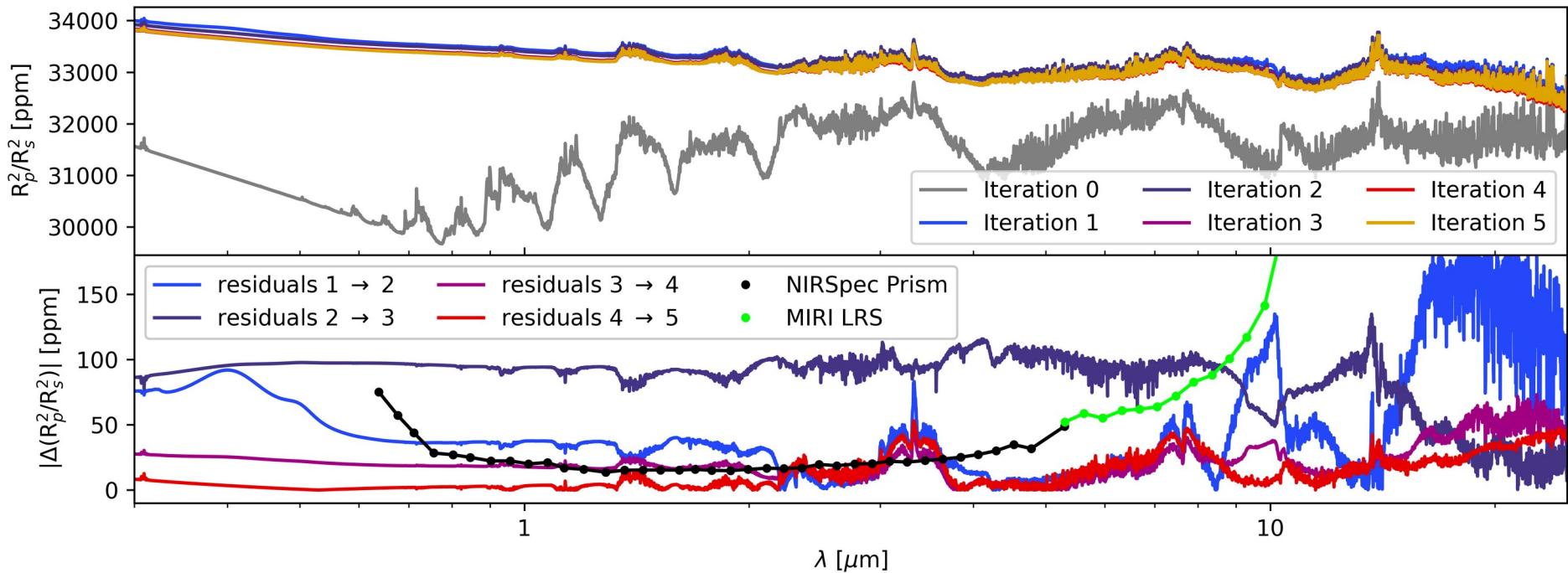


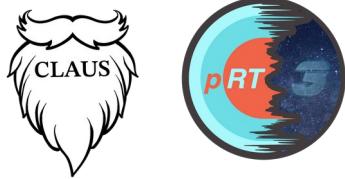
Is it observable?



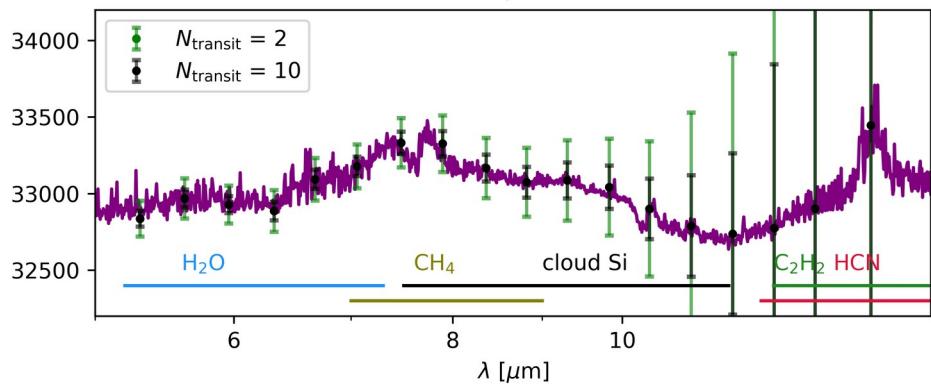
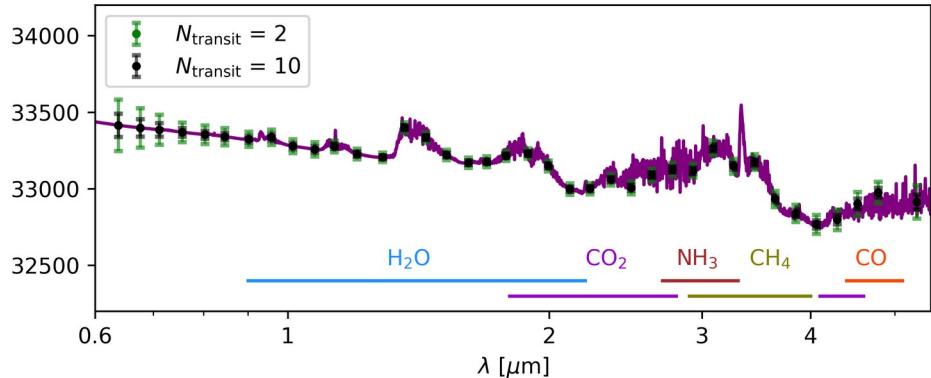


Is it observable?

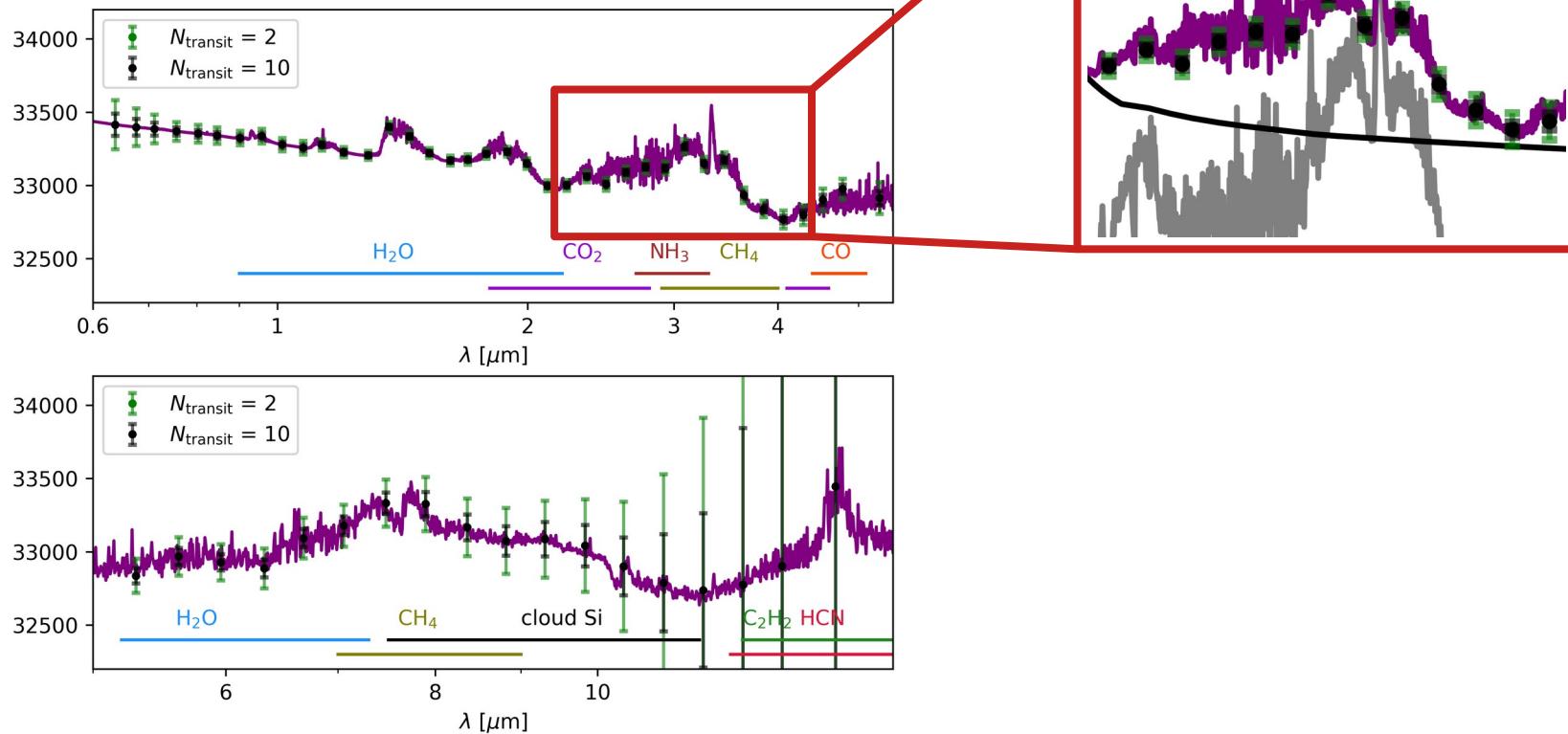




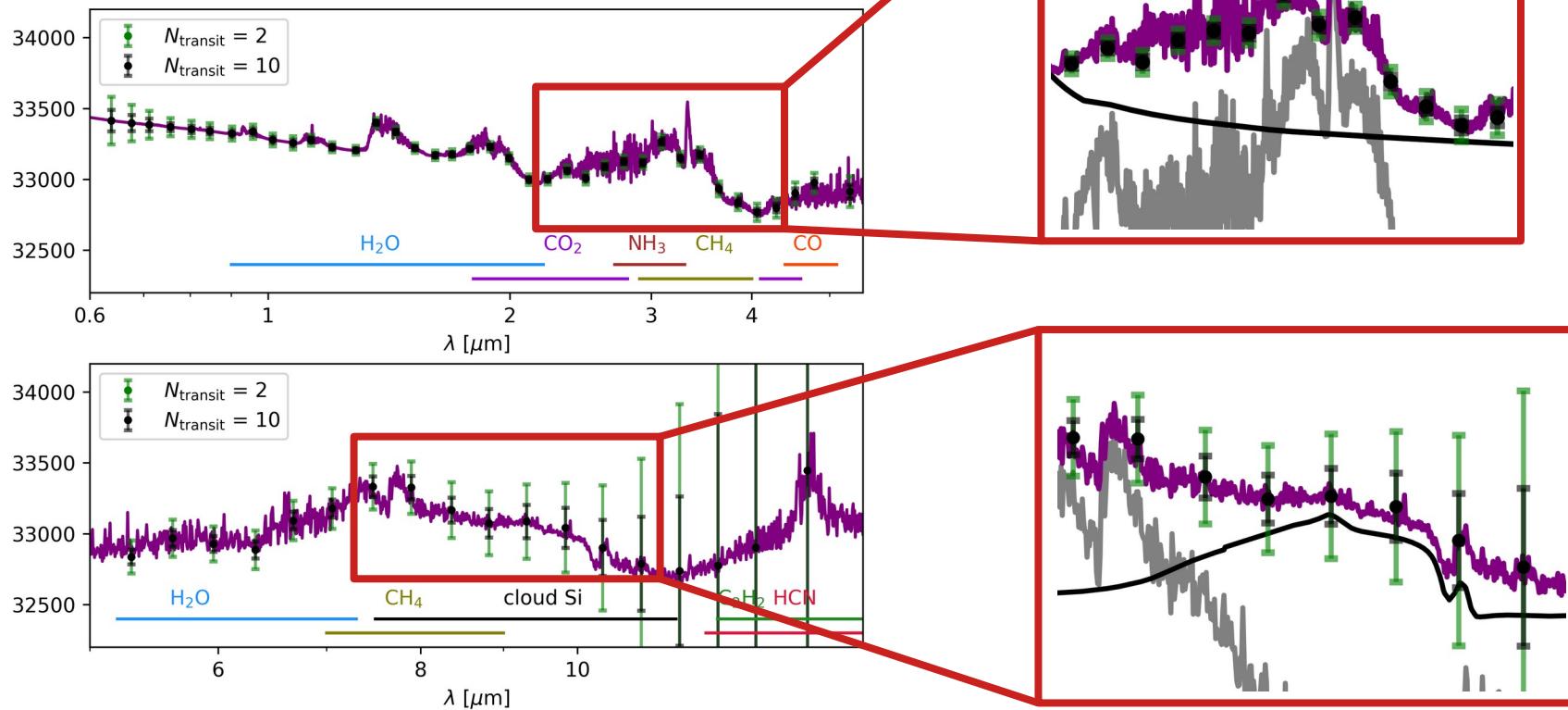
Observing HATS-6b



Observing HATS-6b



Observing HATS-6b



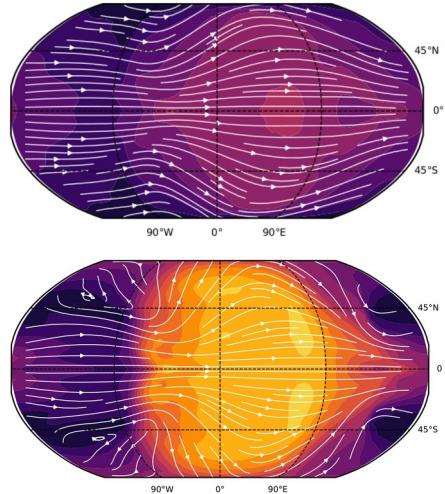
Summary

sven.kiefer@kuleuven.be
Kiefersv.github.io
@ExoSvenK

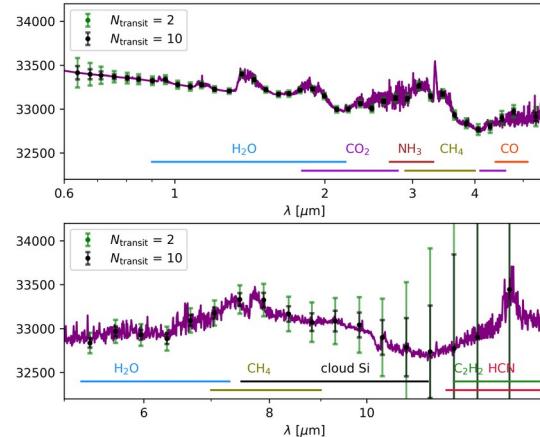


HATS-6 b	
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Diameter: $0.57 R_{\odot}$	
Temperature: 3724 K	
[Fe/H]: 0.2	
M-dwarf	
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Diameter: $0.998 R_J$	
Temperature: 700 K	
[Fe/H]: 0.2	
Warm Saturn	

Clouds impact the climate

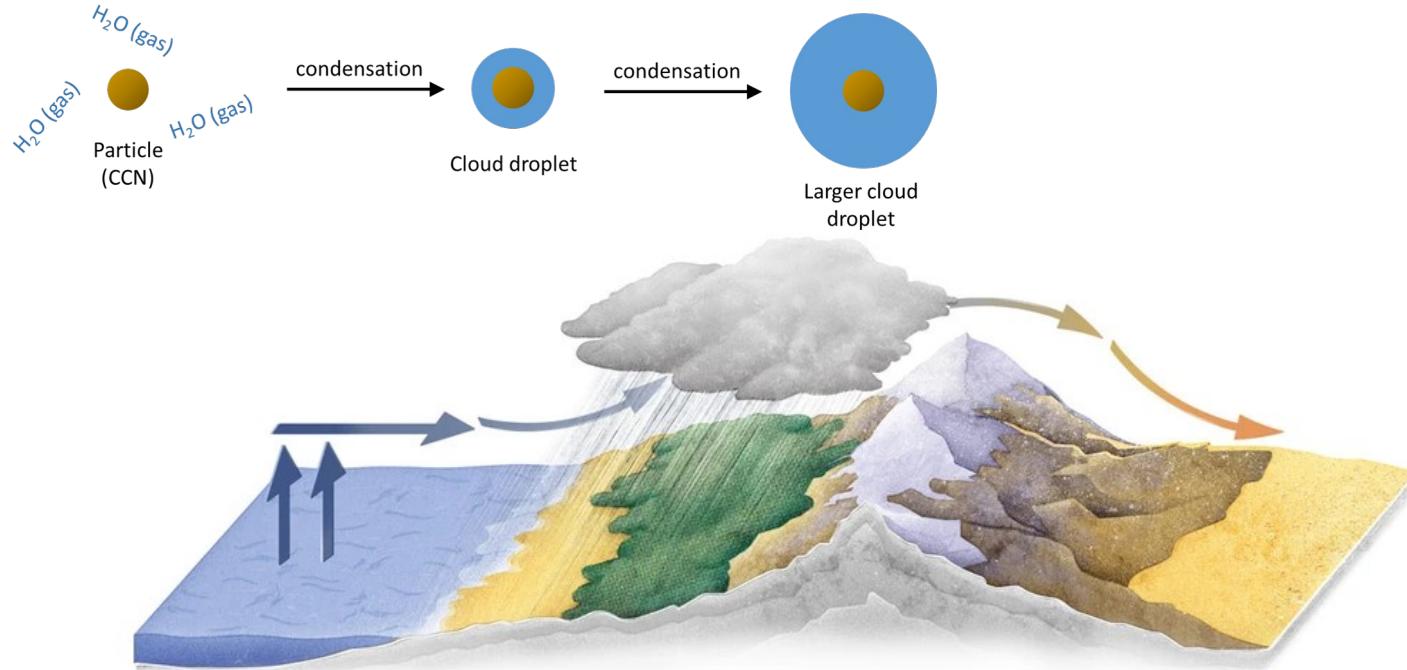


CH₄ and clouds might be observed in HATS-6b



Additional Slides

Clouds on Earth



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

Cloud formation

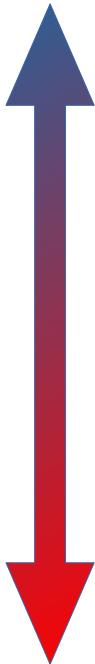
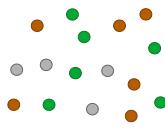
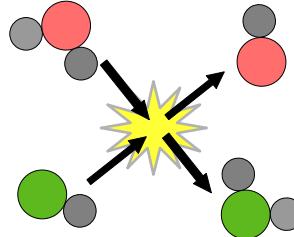


Image altered from Helling (2018)

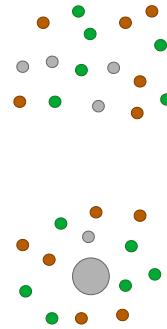
Kinetic Chemistry



For this study:

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

Cloud formation



Nucleation

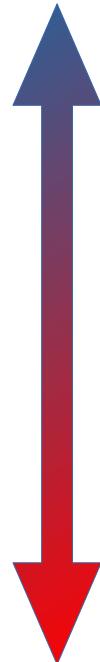
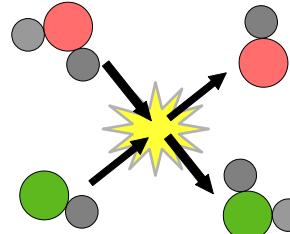
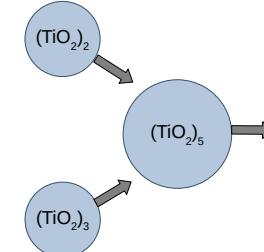


Image altered from Helling (2018)

Kinetic Chemistry



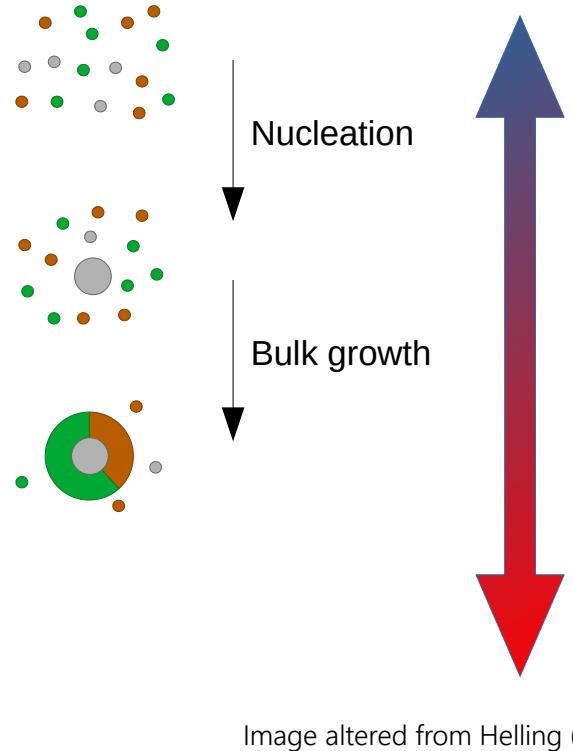
Kinetic nucleation



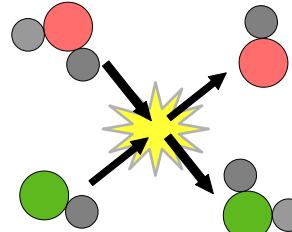
Nucleation:

- Species: $\text{TiO}_2[\text{s}]$
- Maximum size: $(\text{TiO}_2)_{15}$

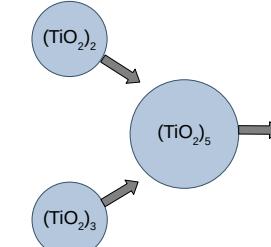
Cloud formation



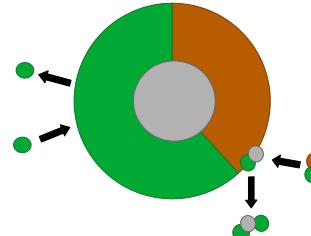
Kinetic Chemistry



Kinetic nucleation



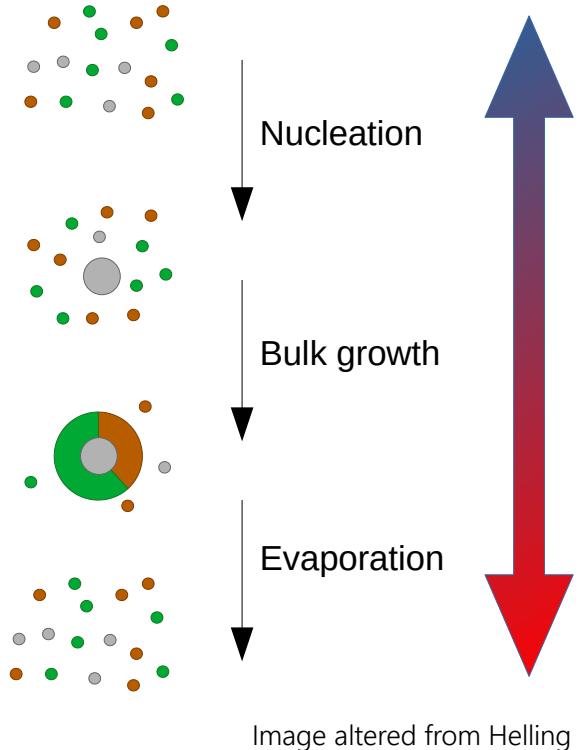
Bulk growth



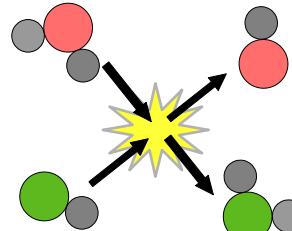
Cloud material

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

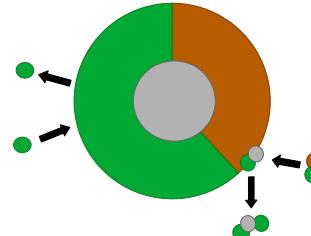
Cloud formation



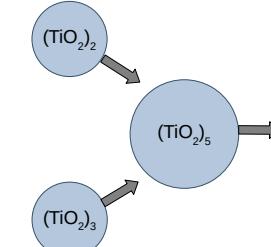
Kinetic Chemistry



Bulk growth



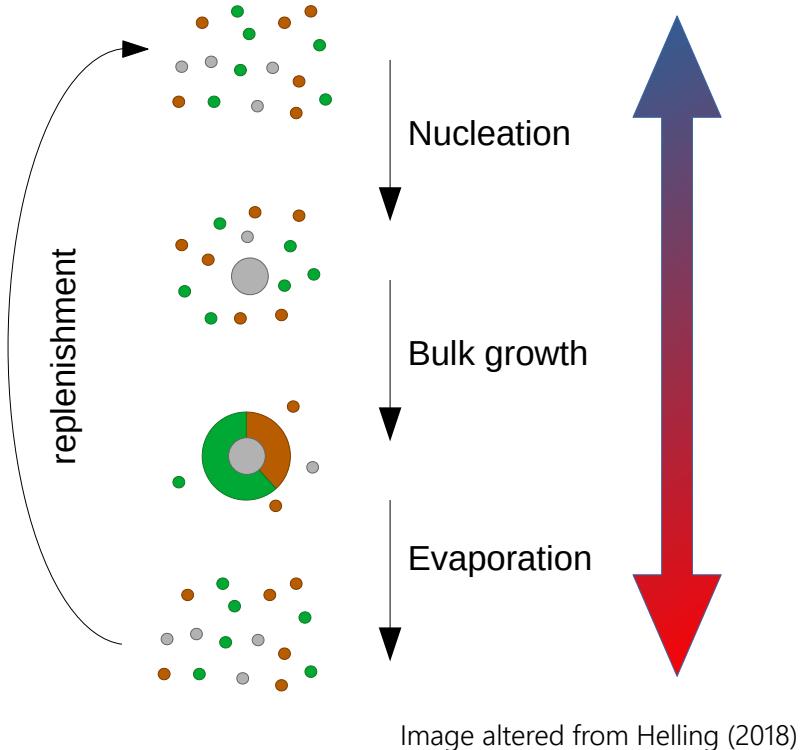
Kinetic nucleation



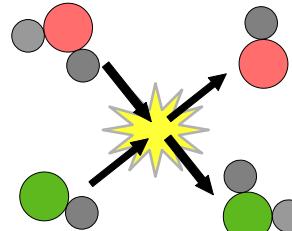
Cloud material

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

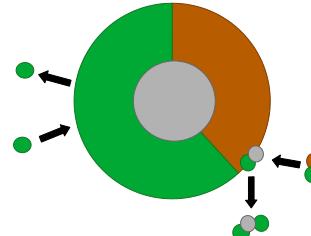
Cloud formation



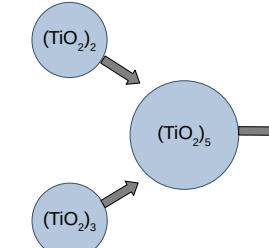
Kinetic Chemistry



Bulk growth



Kinetic nucleation

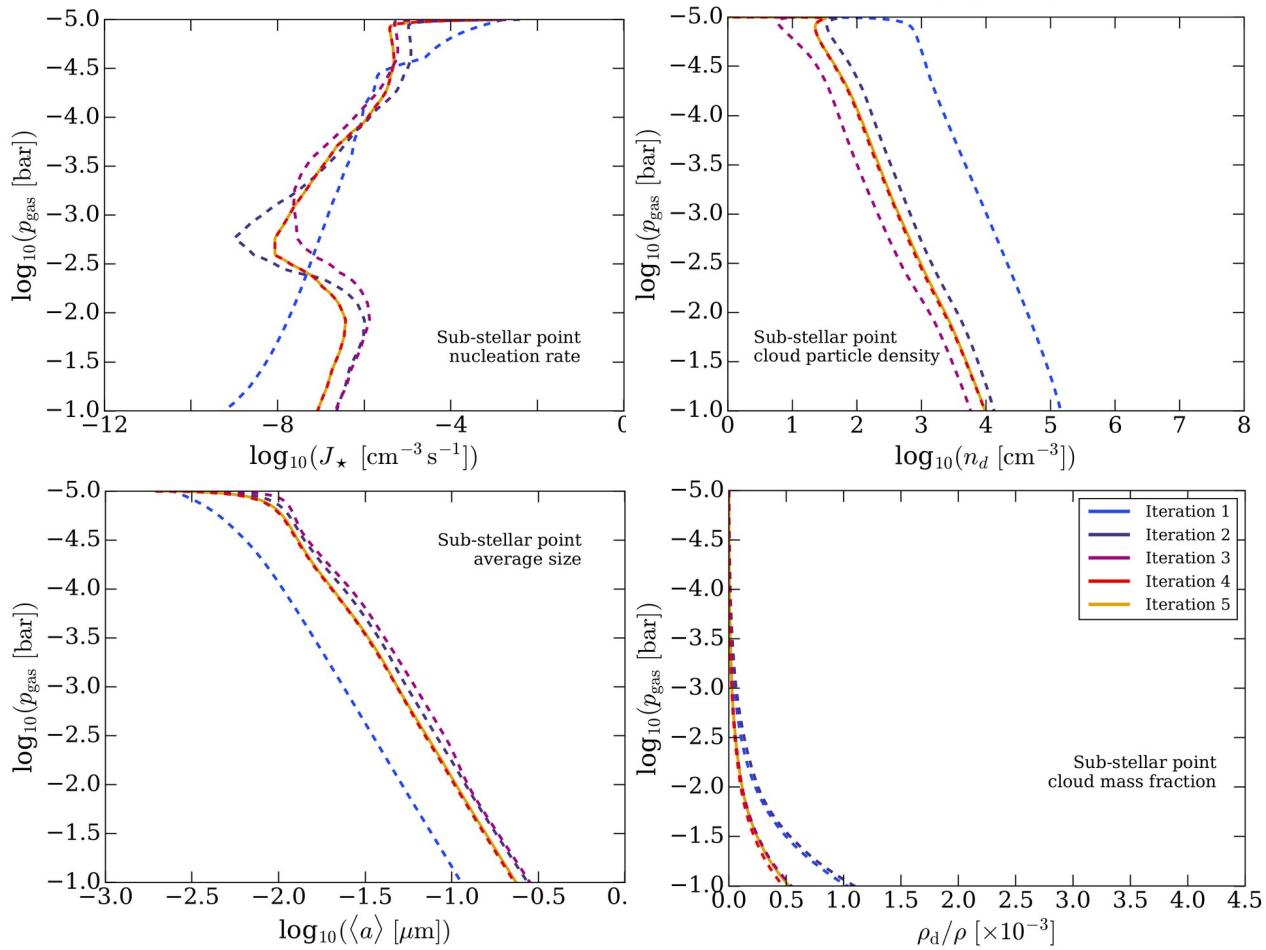
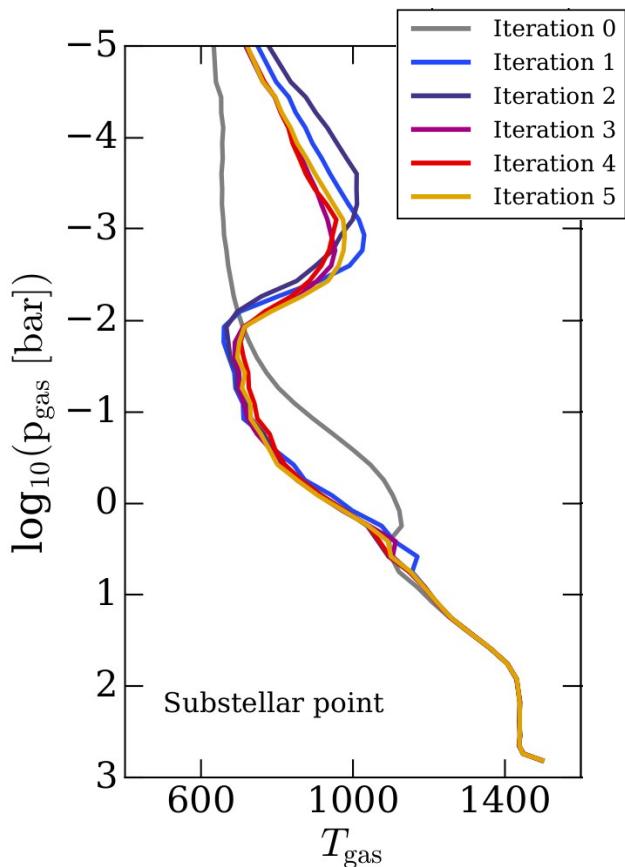


Cloud material

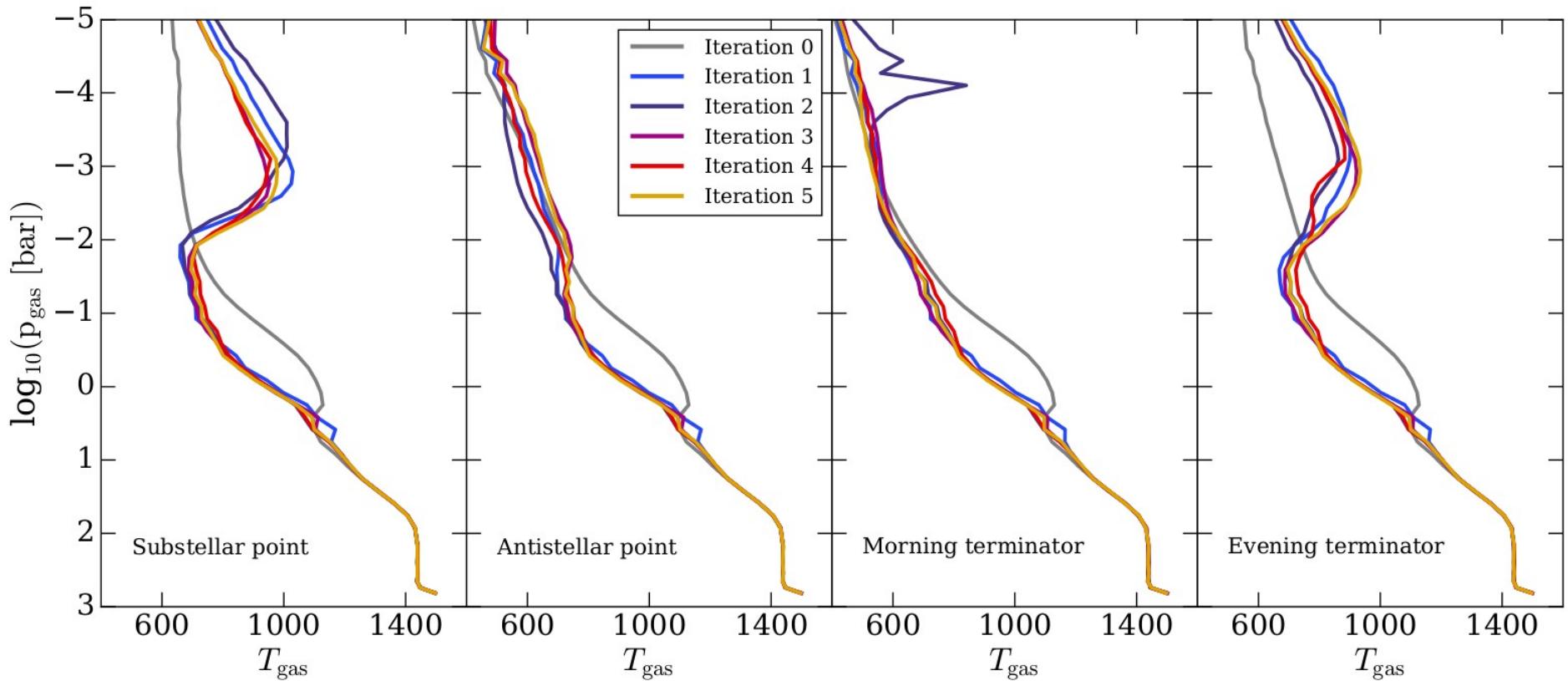
TiO ₂	FeO	NaCl
Al ₂ O ₃	Fe ₂ O ₃	KCl
SiO	FeS	MnO
SiO ₂	Fe ₂ SiO ₄	Na ₂ S
Mg ₂ SiO ₄	Fe	MnO
MgSiO ₃	CaTiO ₃	CaSiO ₃

Clouds in 3D

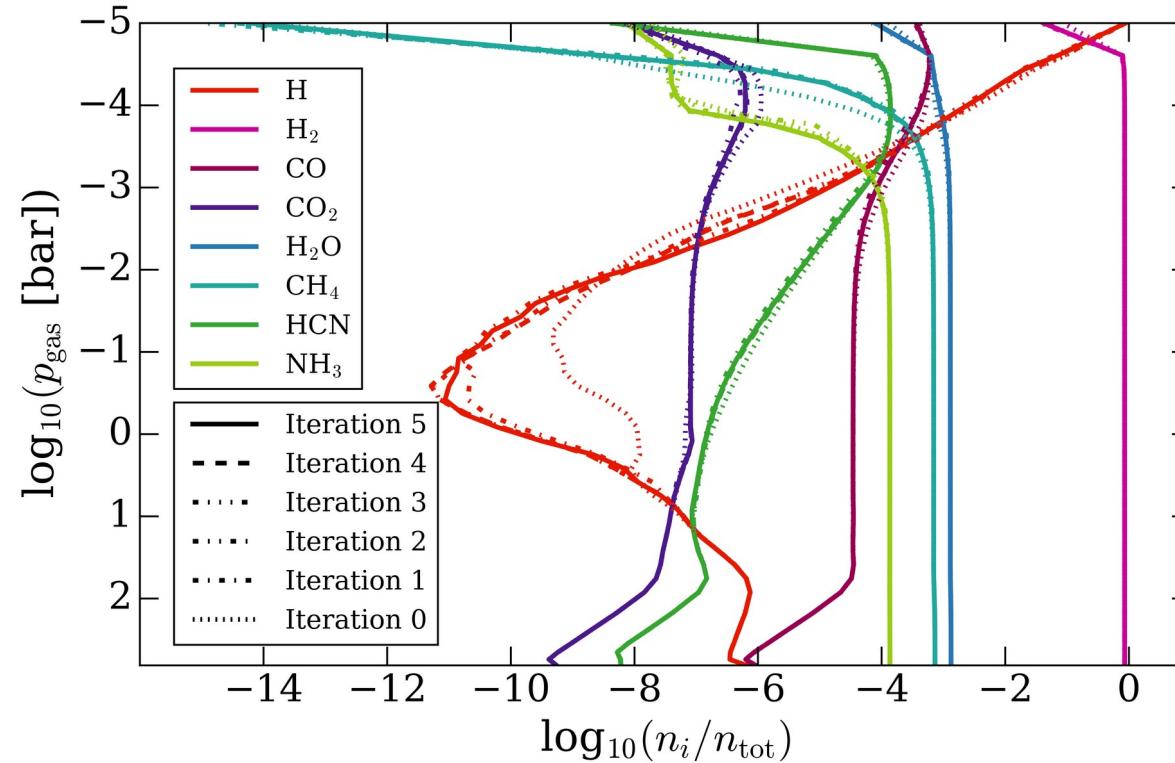
Clouds in 3D



HATS-6b

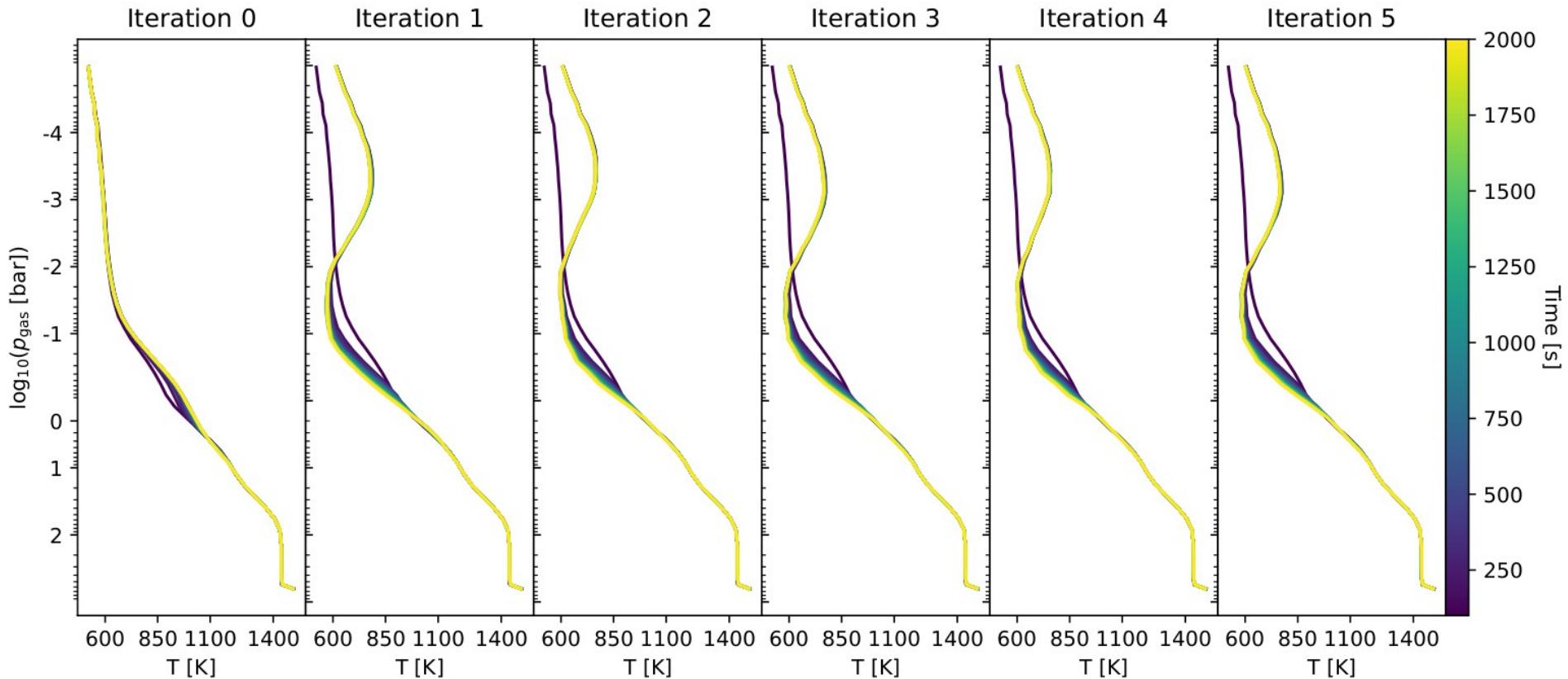


Chemistry

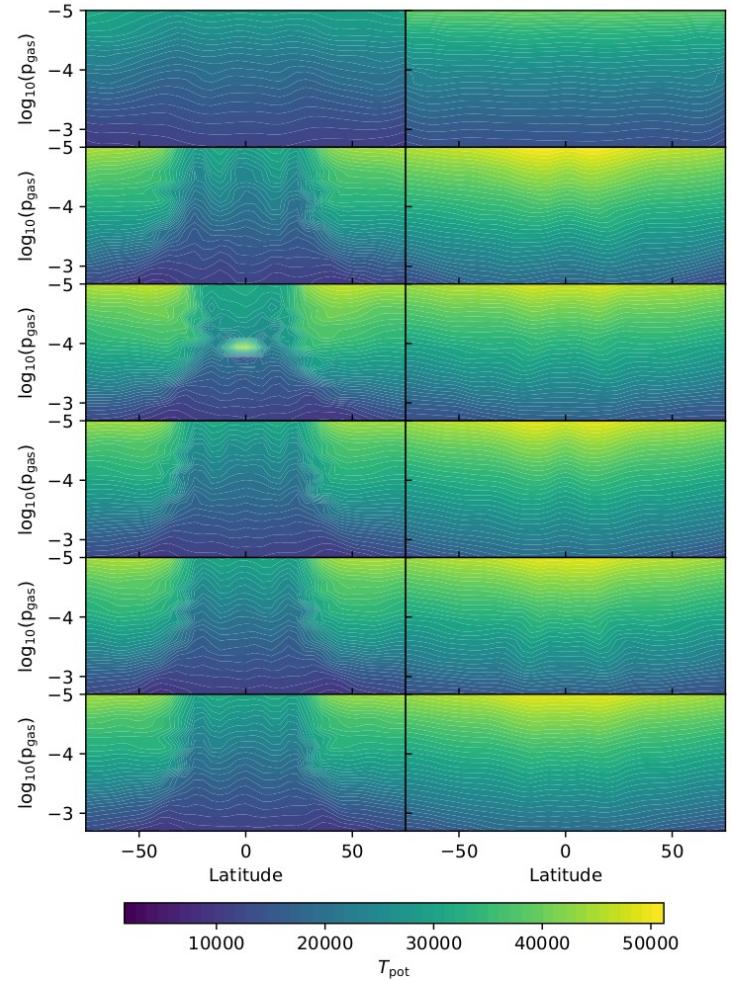
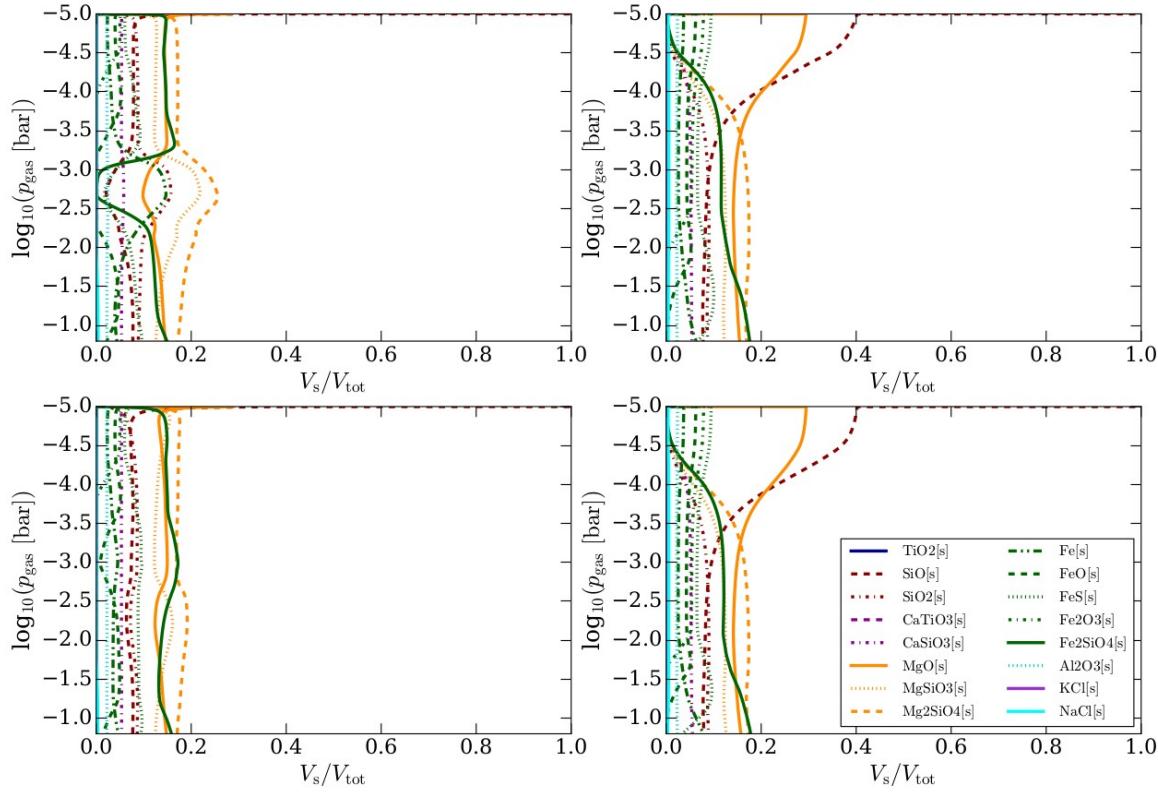


Chemistry

HATS-6b



HATS-6b



Observing HATS-6b

