Modeling Exoplanetary Atmospheres in Nearby Systems

Emily Rauscher

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Disclaimers

- 1 year ≈ 25 minutes
  - also means I'm not necessarily crediting originators of ideas
- This is not a pedagogical talk
  - see Fortney's "Modeling Exoplanetary Atmospheres: An Overview", arXiv:1804.08149
  - (also related Atmospheric Physics and Observing Techniques reviews by Grassi and Sing, respectively)
- I'm biased
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not observations
my 3D bias

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near-photospheric pressures, ~1 mbar – 1 bar
NOT tenuous, evaporating layers

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nod to observations
bias: gaseous, hot, transiting

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Understanding dynamical regimes

Hot Jupiters, [“Normal”] Jupiters, Young Jupiters, Non-Jupiters …

Questions:

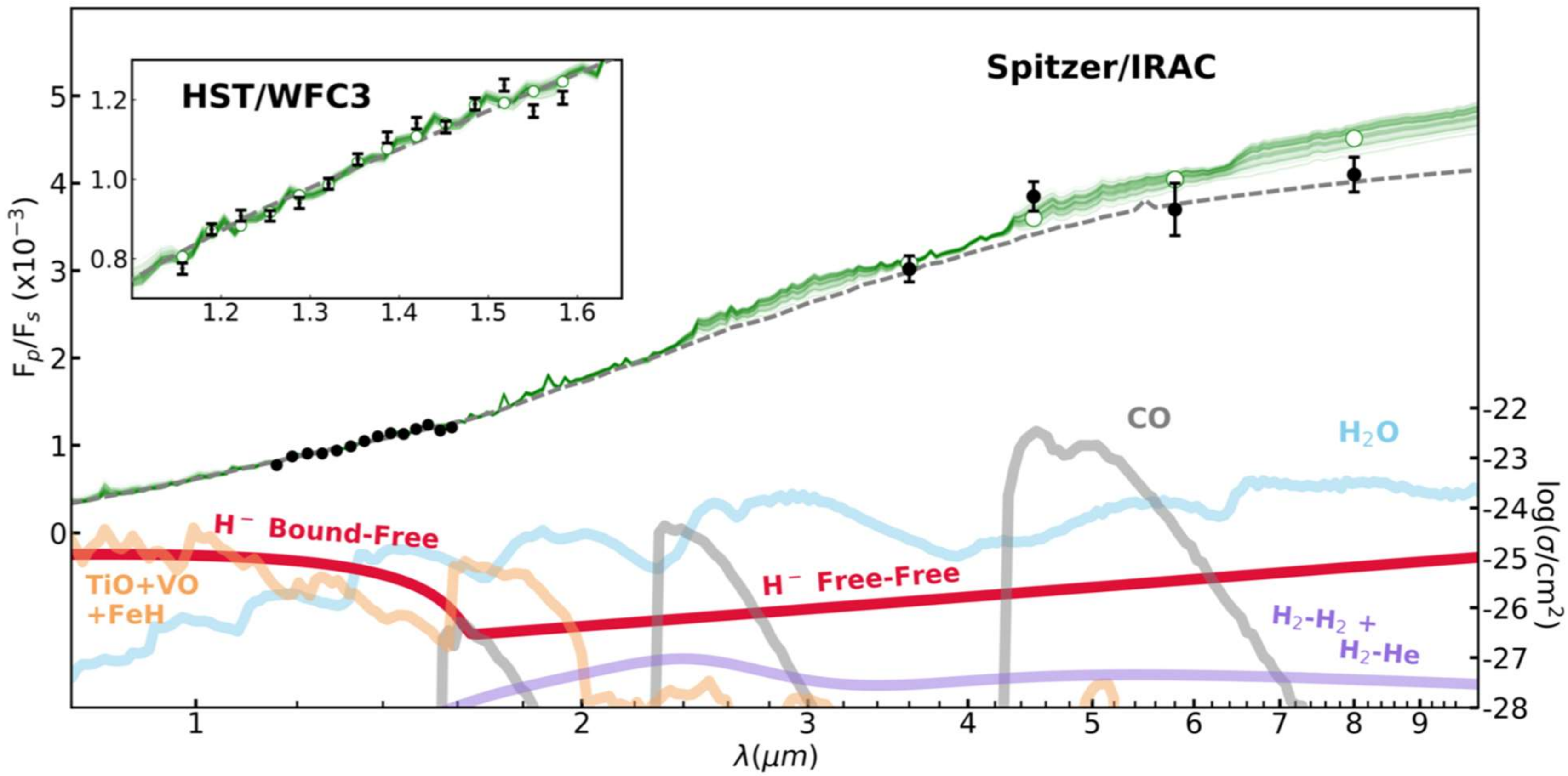
- Do we have the “standard” hot Jupiter circulation correct?
  - What is the dynamical mechanism at work? (Hammond & Pierrehumbert 2018)
  - What about sub-grid physics (shocks, dissipation)? (Ryu et al. 2018)
- Do the “standard” equations work for warm, slowly rotating mini-Neptunes/super-Earths? (Mayne et al. 2018)
- How does dynamical mixing depend on all the things? (Zhang & Showman 2018a,b; Menou 2018)
- Dynamical variability/oscillations in brown dwarfs and Jupiter-like planets? (Showman et al. 2018)

Ultra-hot Jupiters

Exotic (?) physics

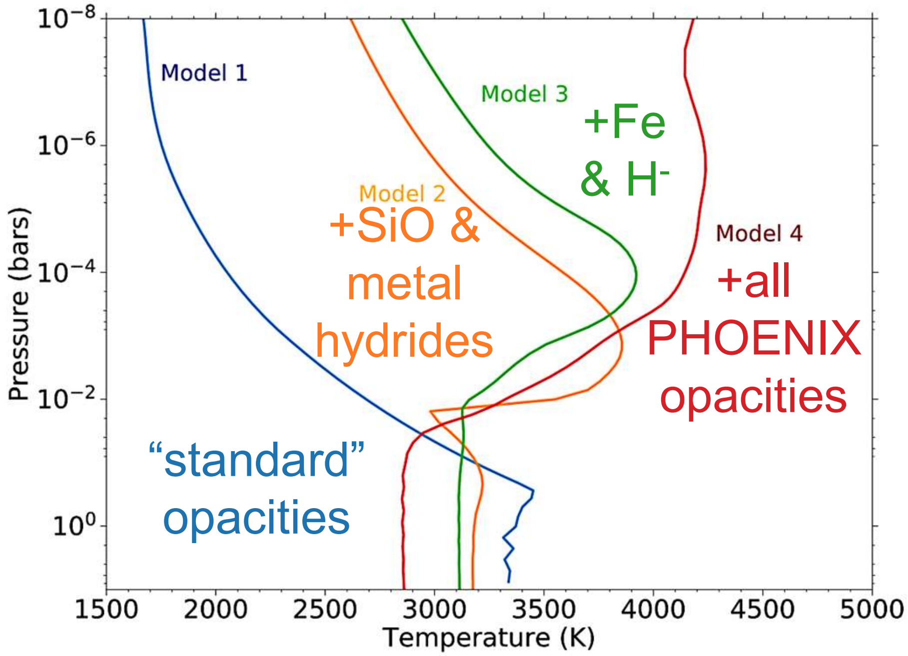
Stellar-ish atmospheres

Featureless spectra: H^- opacity



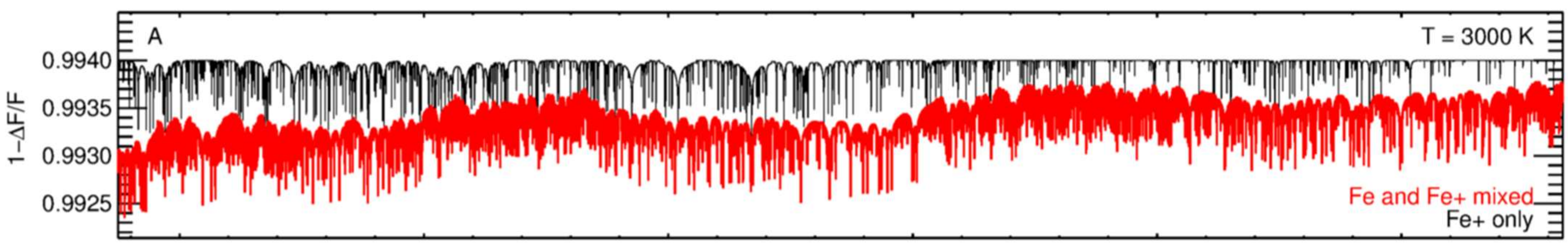
Arcangeli et al. (2018)

Stellar-ish atmospheres



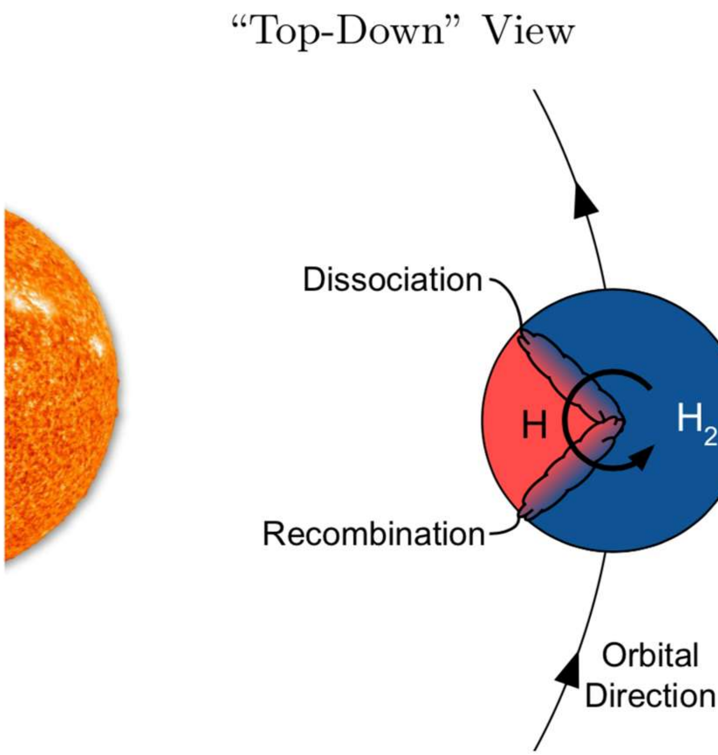
Lothringer et al. (2018)

- Dissociated H, metals, and Fe are important opacities
- Create temperature inversions (too hot for TiO/VO)

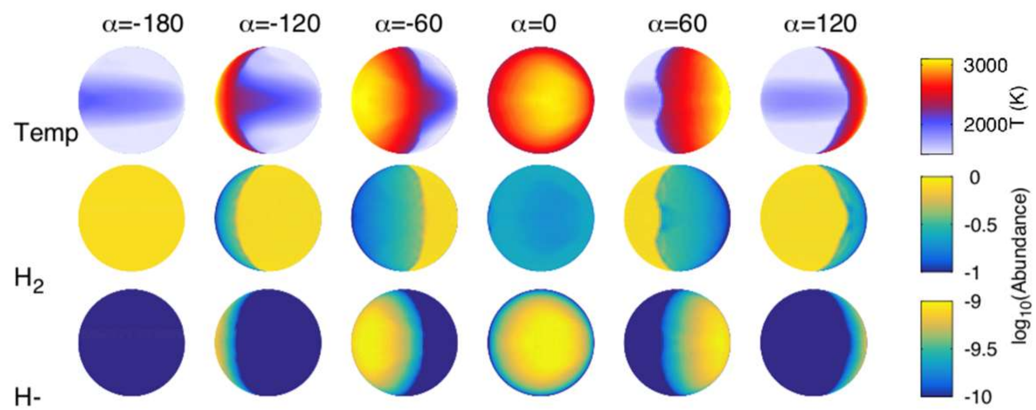


Kitzmann et al. (2018) … and see Hoeijmakers et al. (2018)

Day-night H differences

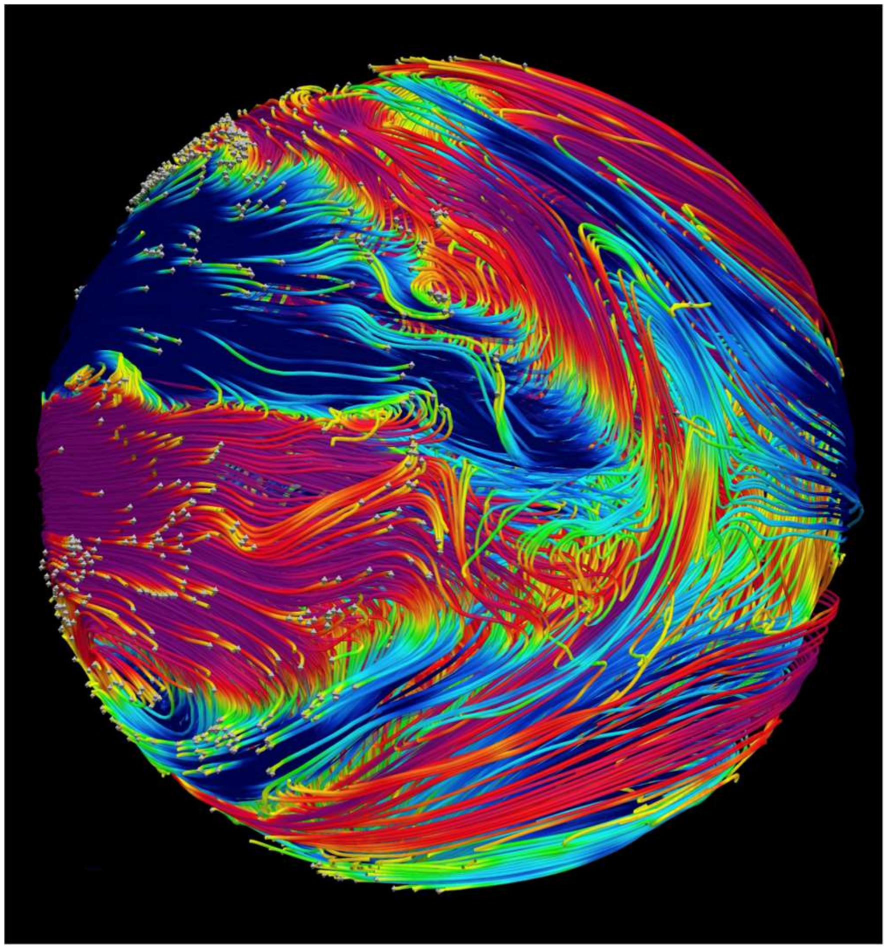


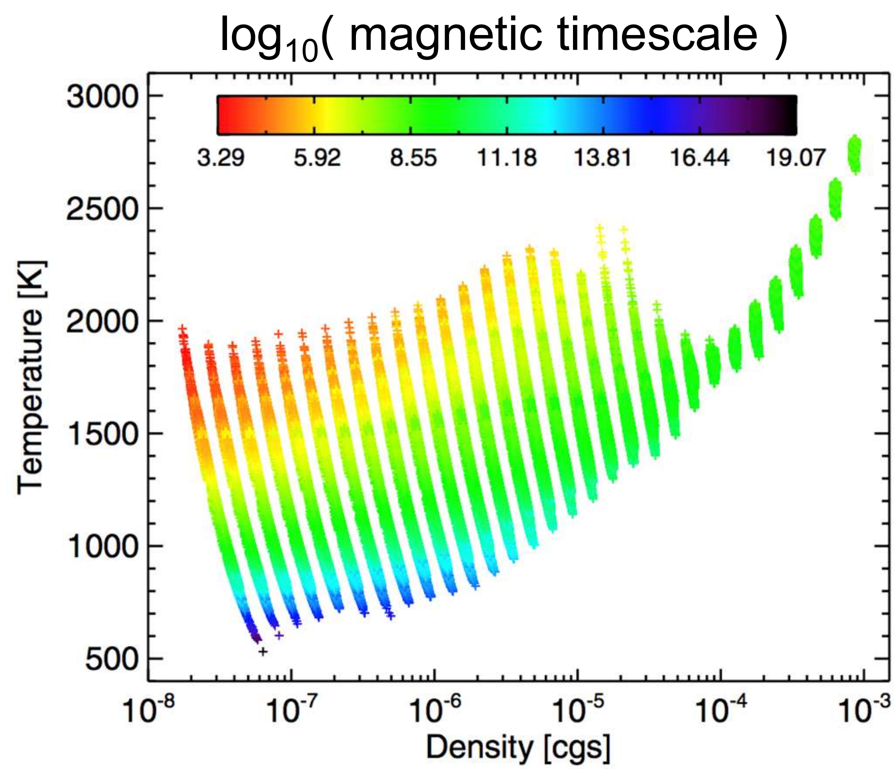
Bell & Cowan (2018)



Parmentier et al. (2018)

MHD atmospheres





Rauscher & Menou (2013)

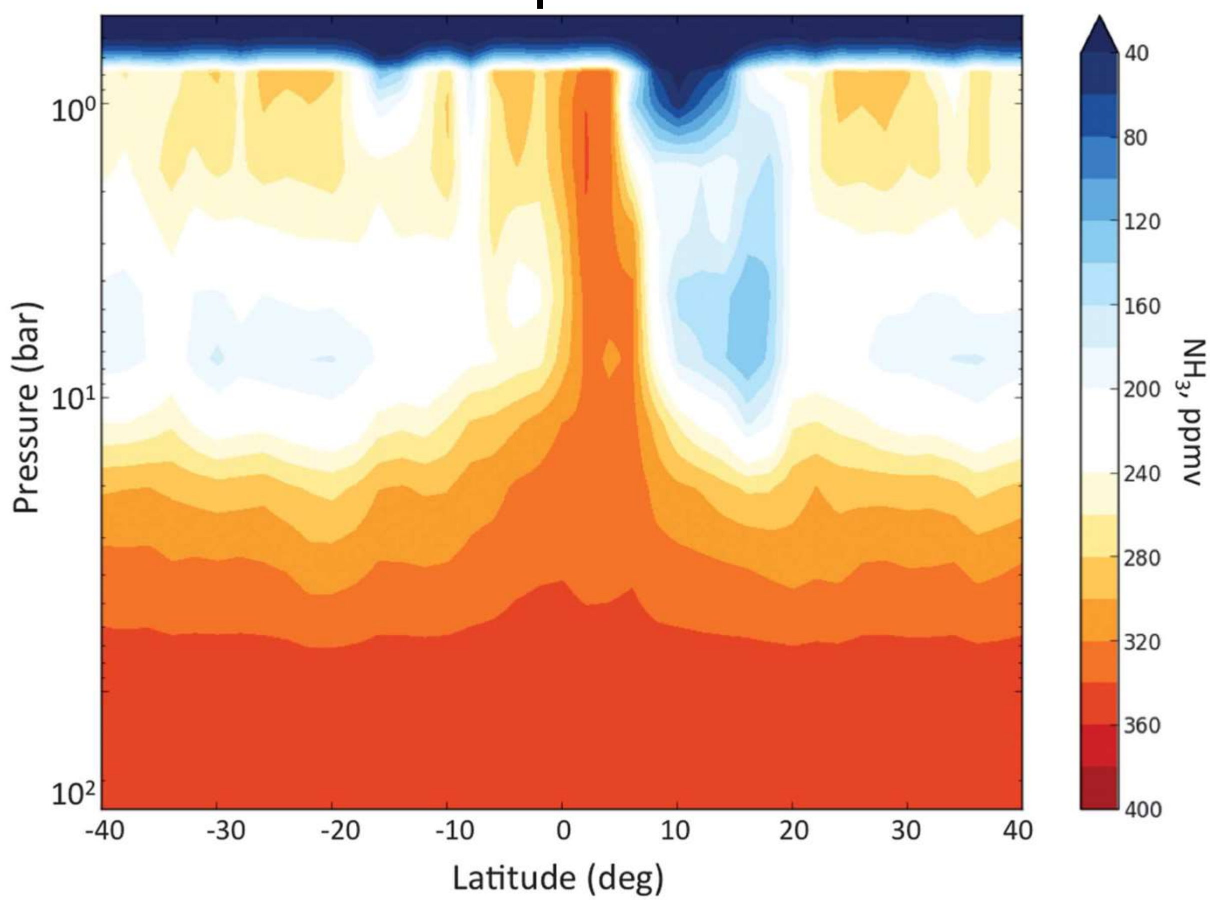
Rogers (2017)

Chemistry

Disequilibrium, photo-ionization

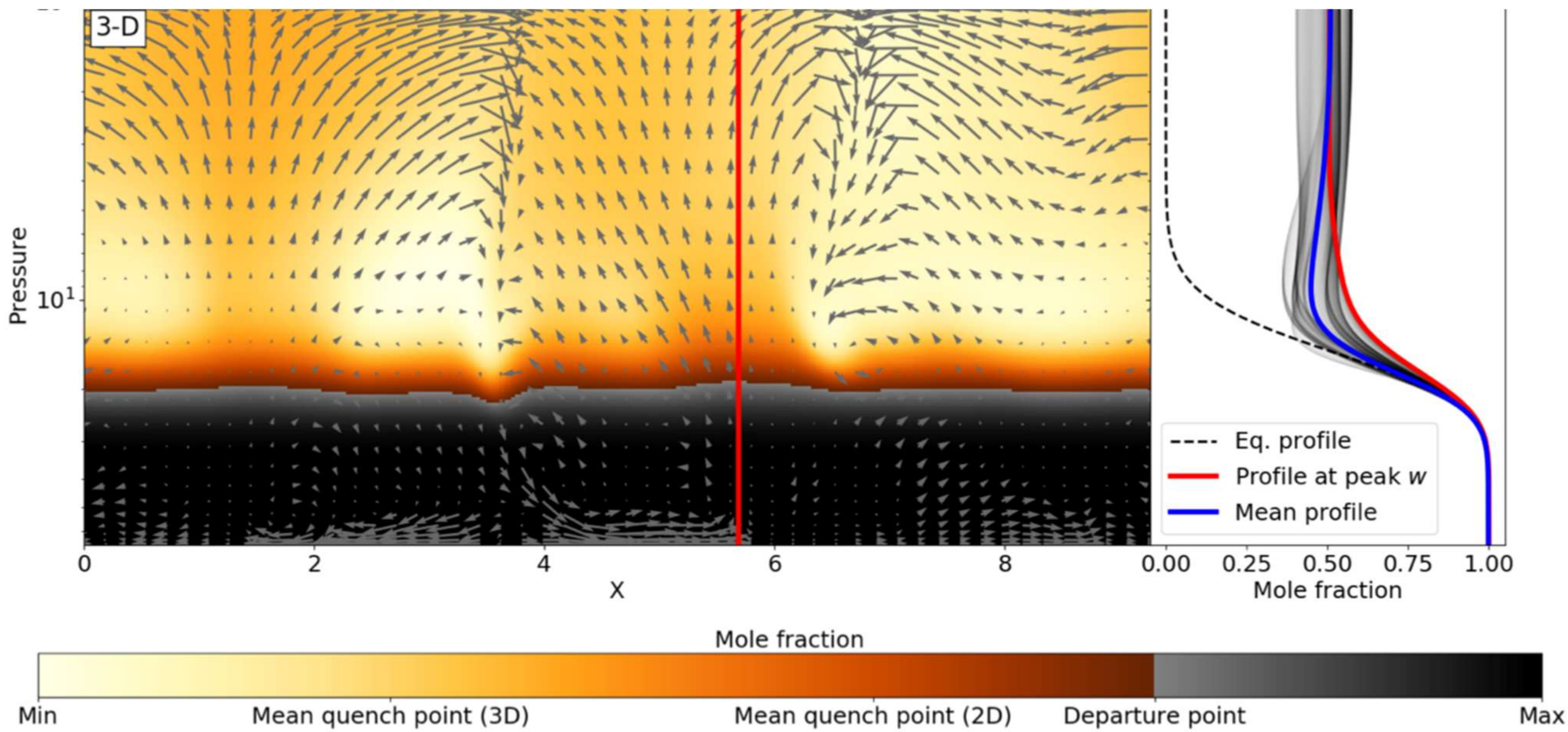
Multi-dimensional mixing in convective atmospheres

Jupiter



Bolton et al. (2017)

Multi-dimensional mixing in convective atmospheres

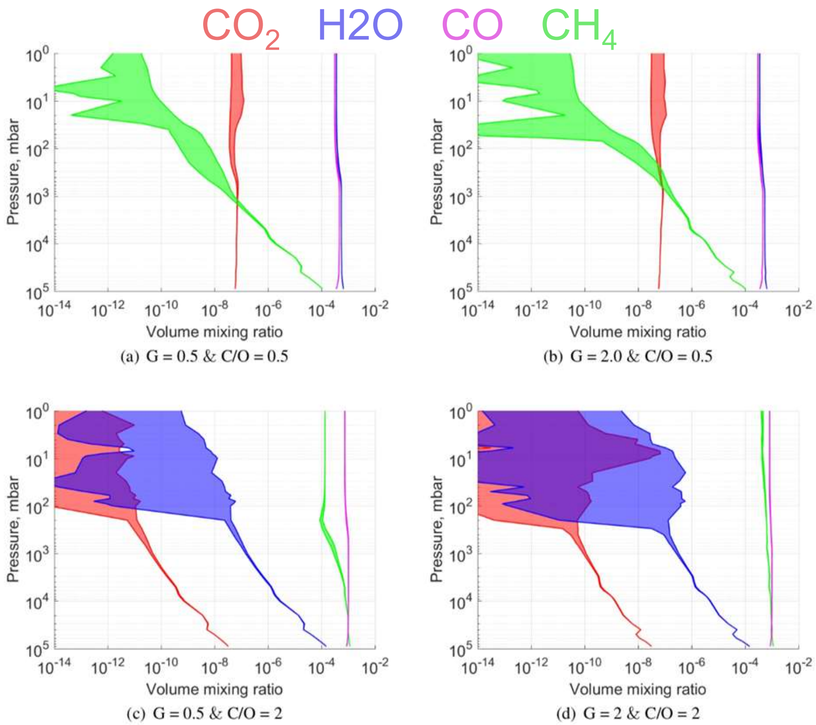


Bordwell et al. (2018)

Multi-dimensional mixing in radiative atmospheres

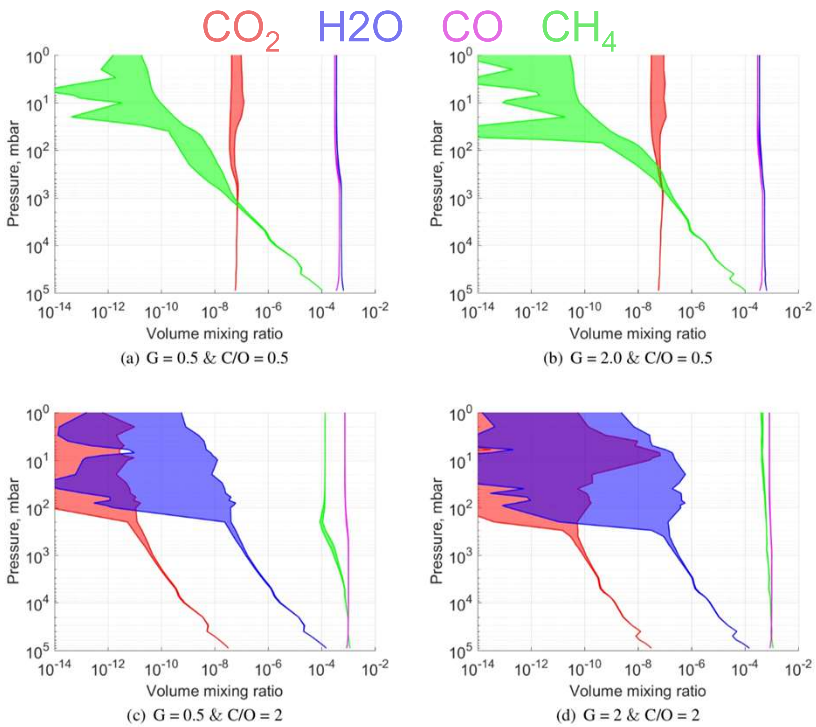
Multi-dimensional mixing in radiative atmospheres

Mendonça et al. (2018)

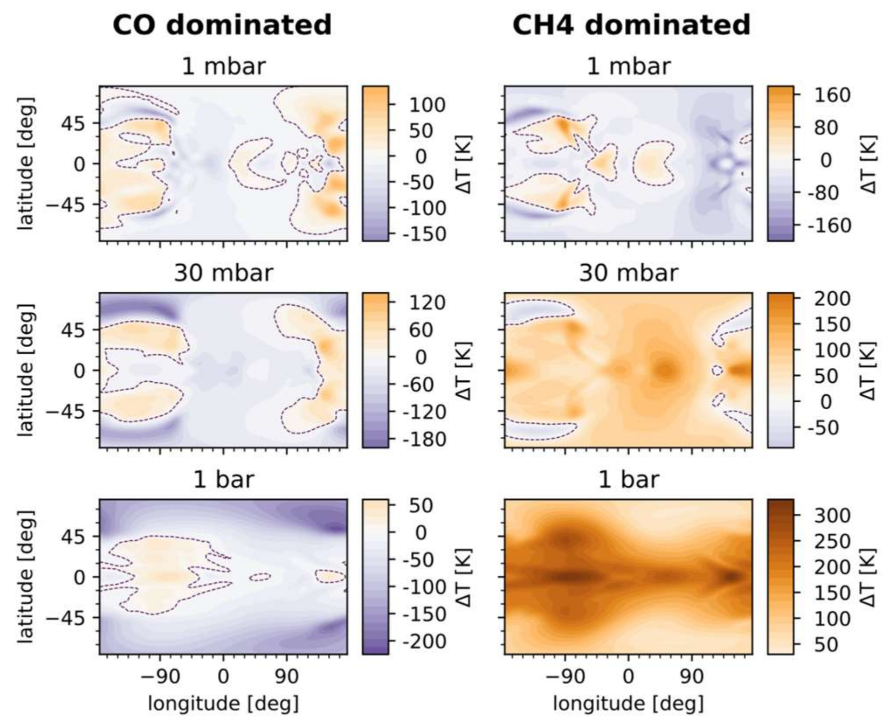


Multi-dimensional mixing in radiative atmospheres

Mendonça et al. (2018)



Steinrueck et al. (2018)



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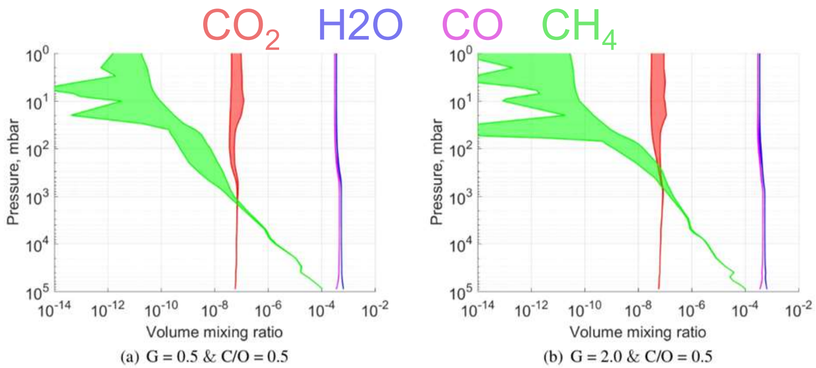

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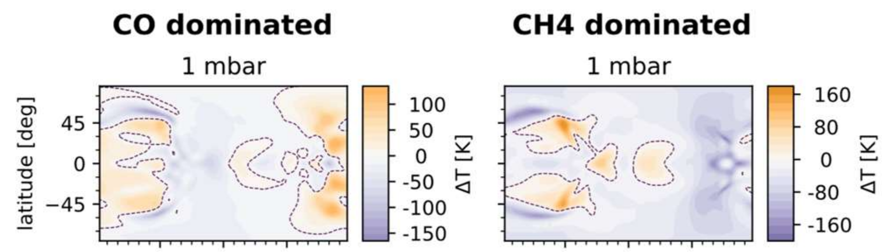
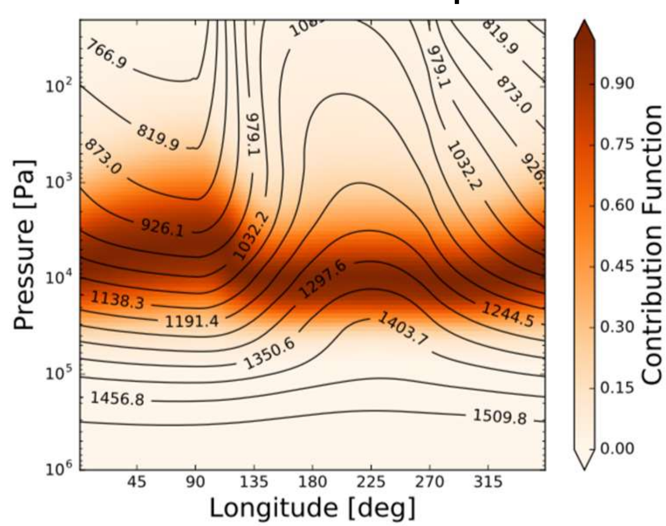


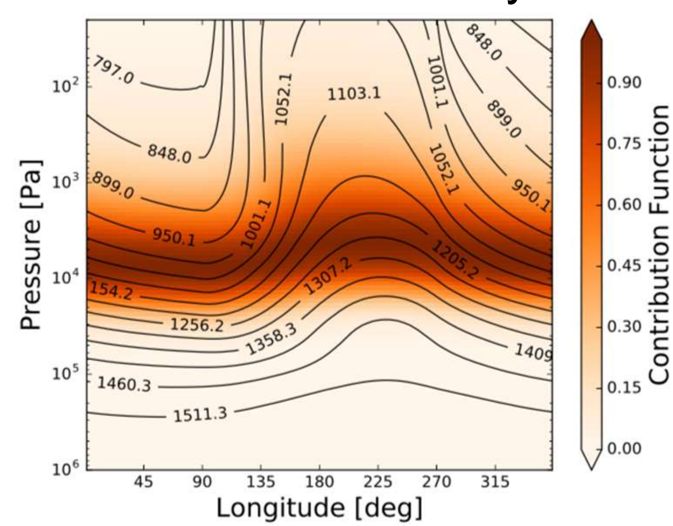
Drummond et al. (2018a,b)

8 micron Spitzer band

Assumed chemical equilibrium



Relaxation chemistry scheme

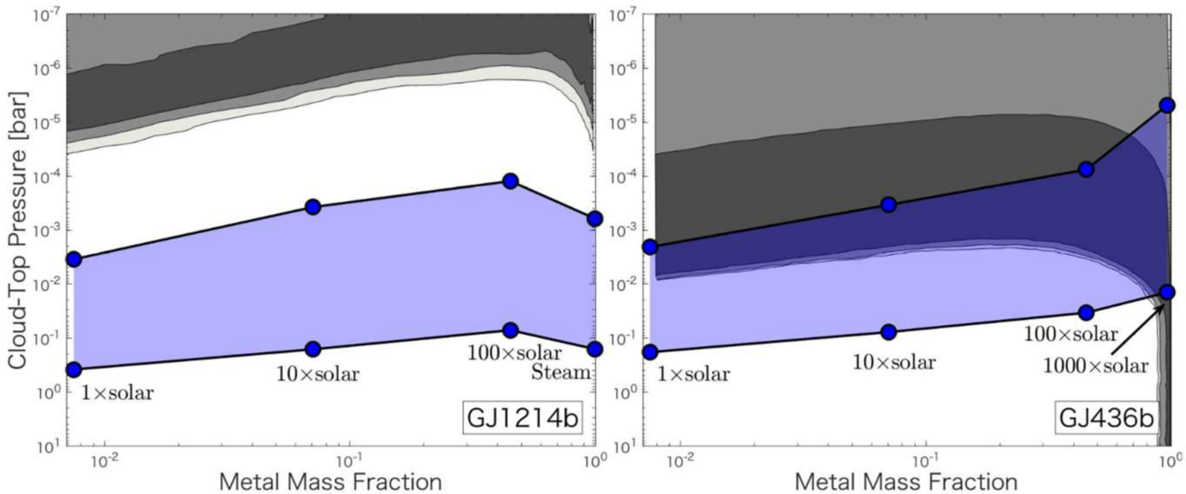


Clouds & Hazes

What are those aerosols?

Detailed cloud microphysics

Comparing predictions to data

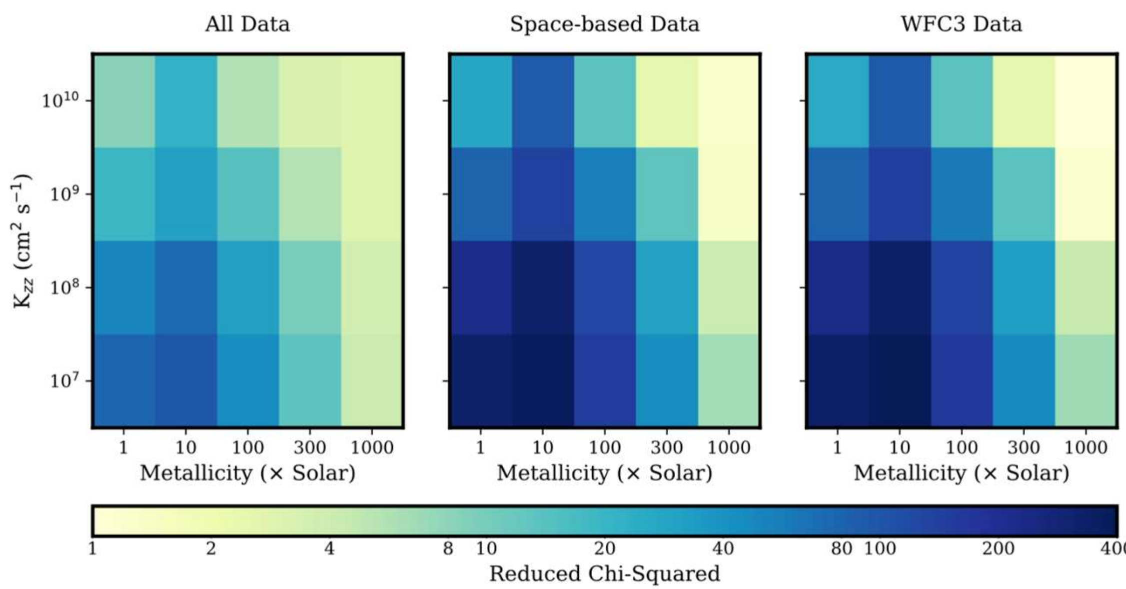


Ohno & Okuzumi (2018)

KCl cloud
prediction
retrieved aerosol level

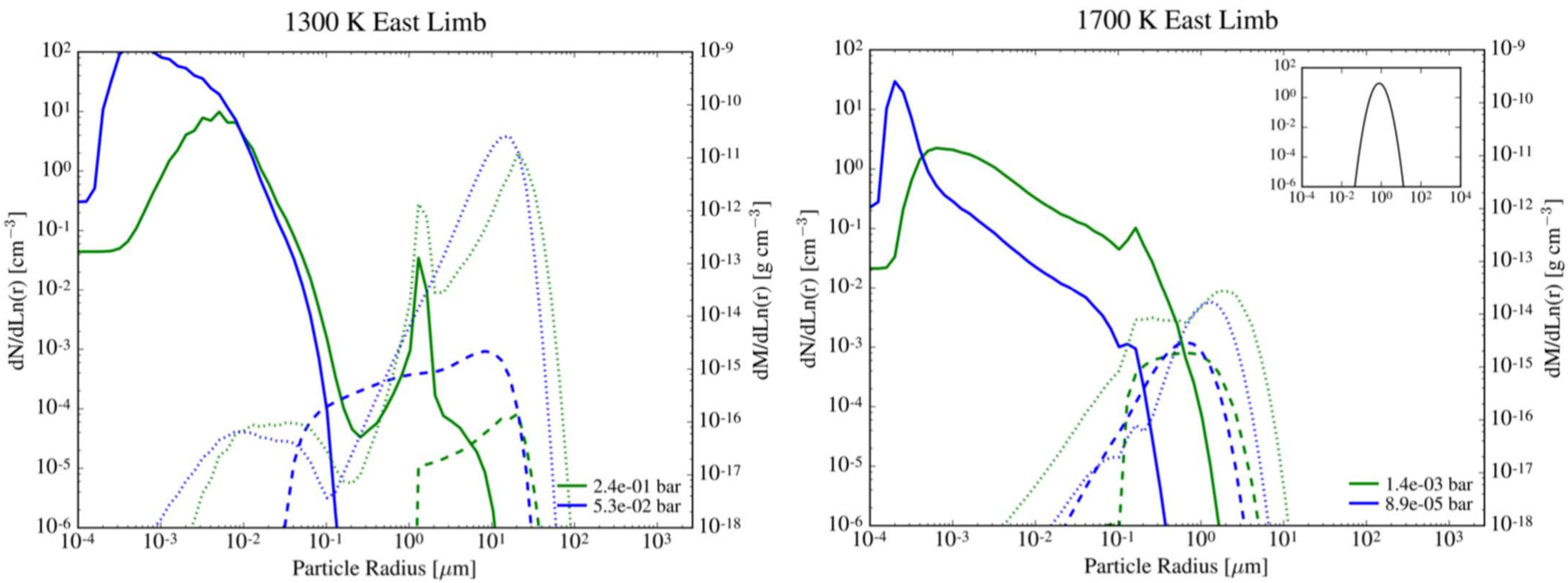
Gao & Benneke (2018)

KCl and ZnS clouds
GJ 1214b data



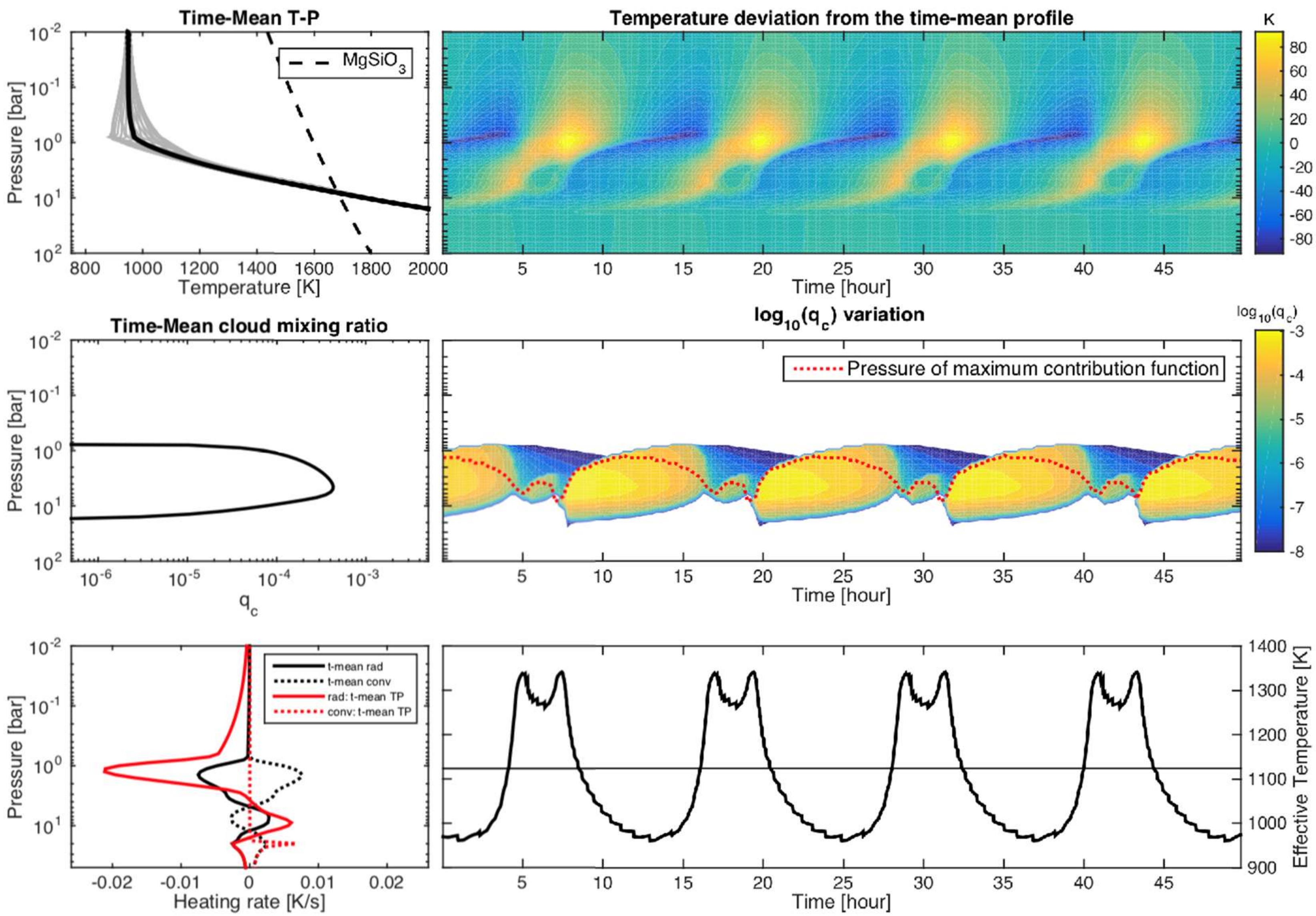
1D microphysics from 3D profile

Titanium clouds
Silicate clouds
Total mass density of clouds



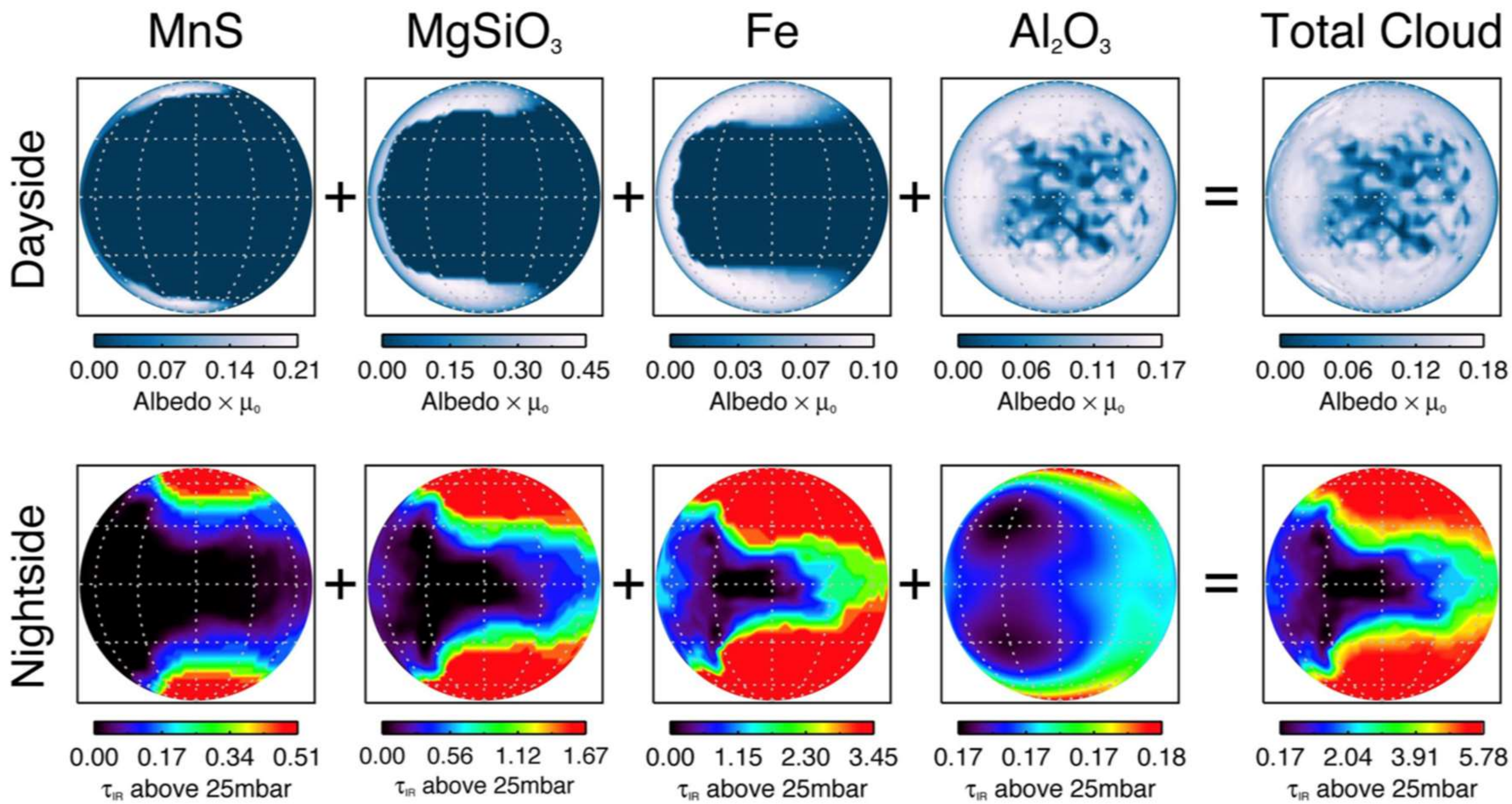
Powell et al. (2018)

Cloud feedback → L/T variability?



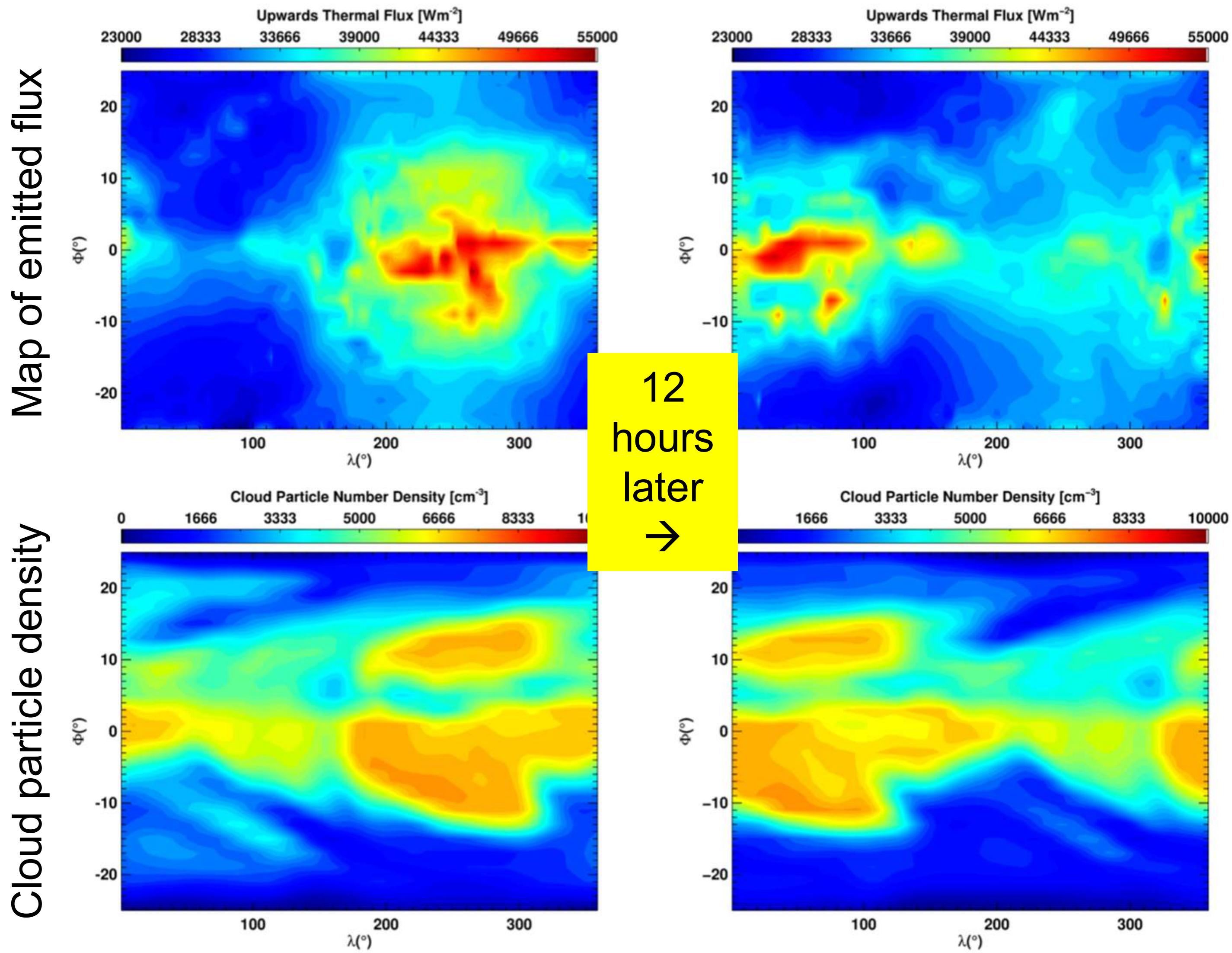
Tan & Showman (2018)

Clouds in 3D w/feedback



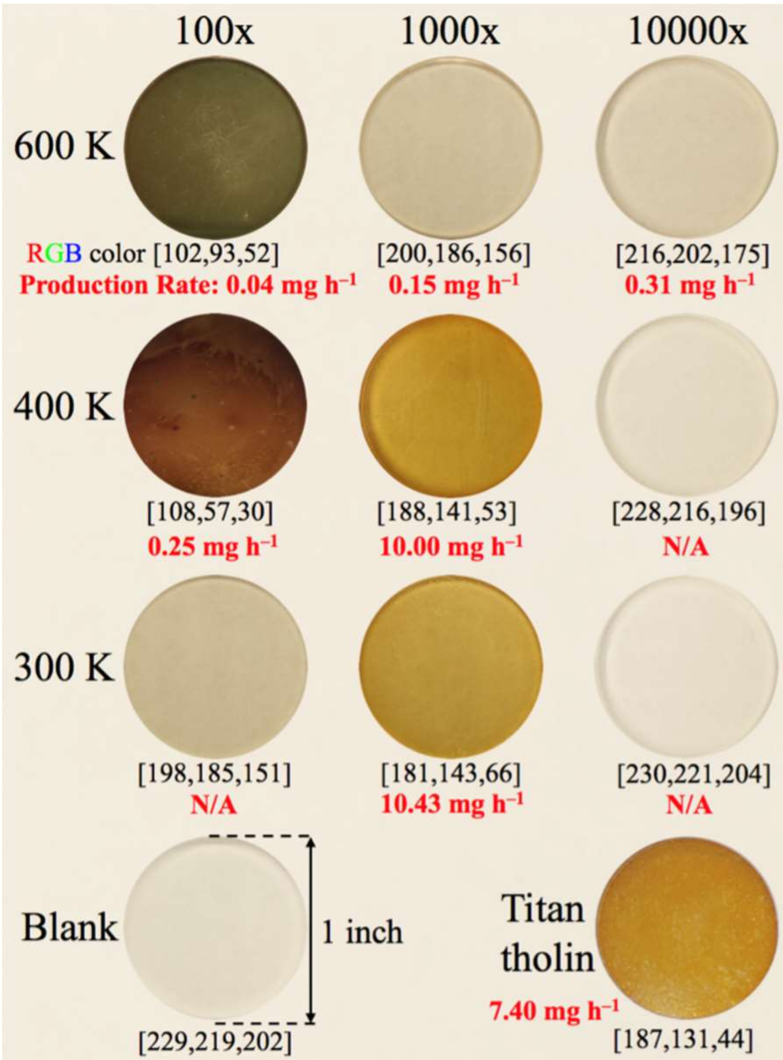
Roman & Rauscher (2018)

Clouds in 3D w/feedback



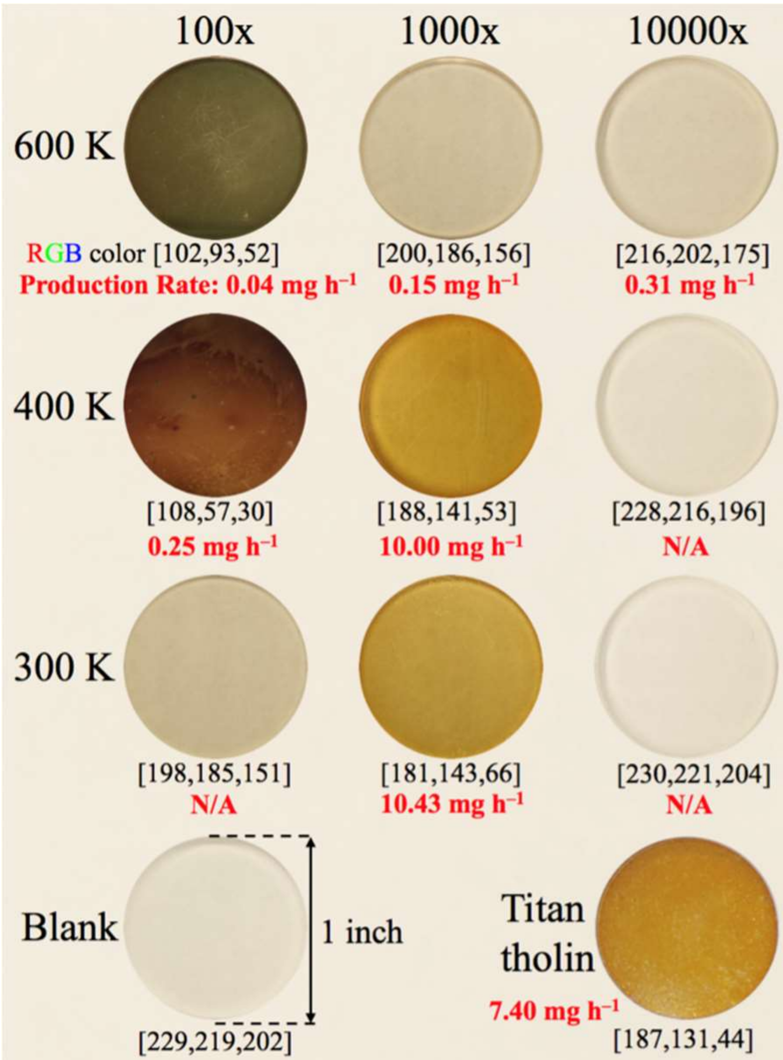
Lines et al. (2018)

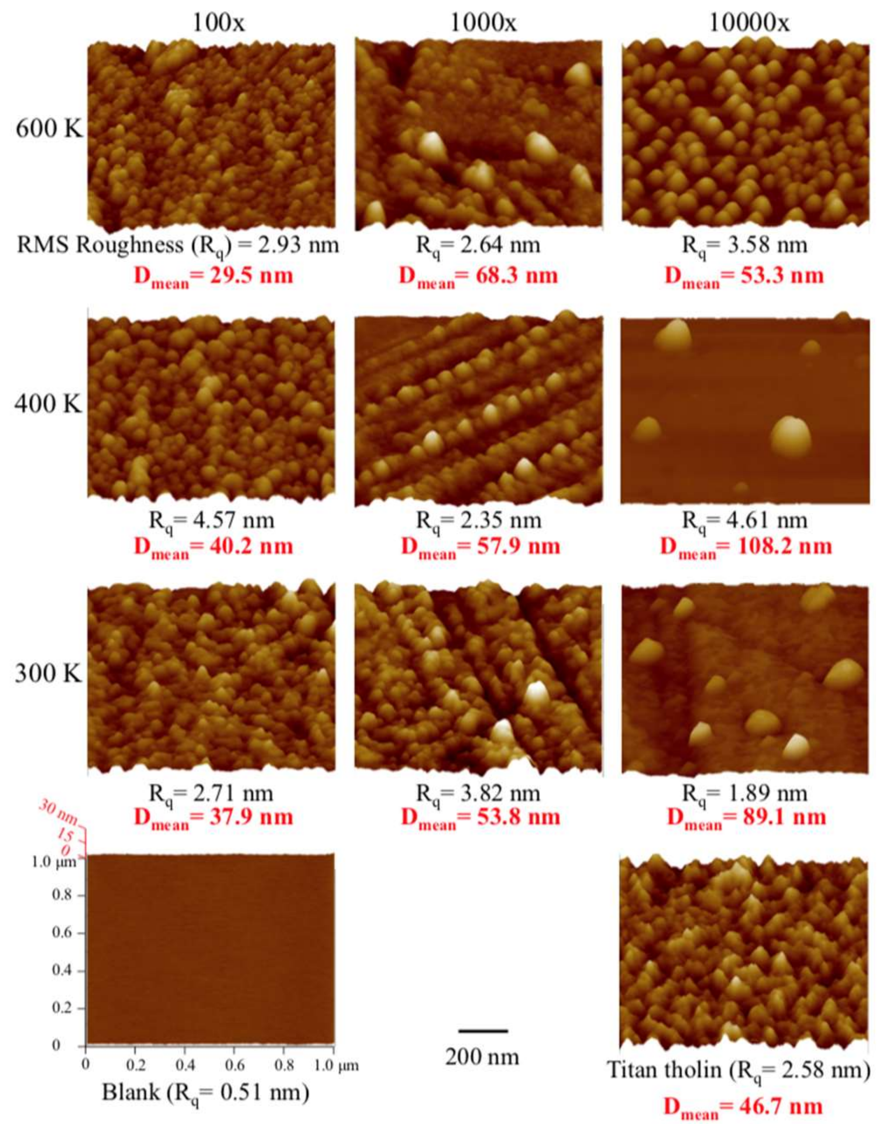
Lab measurements of haze formation



He et al. (2018)

Lab measurements of haze formation





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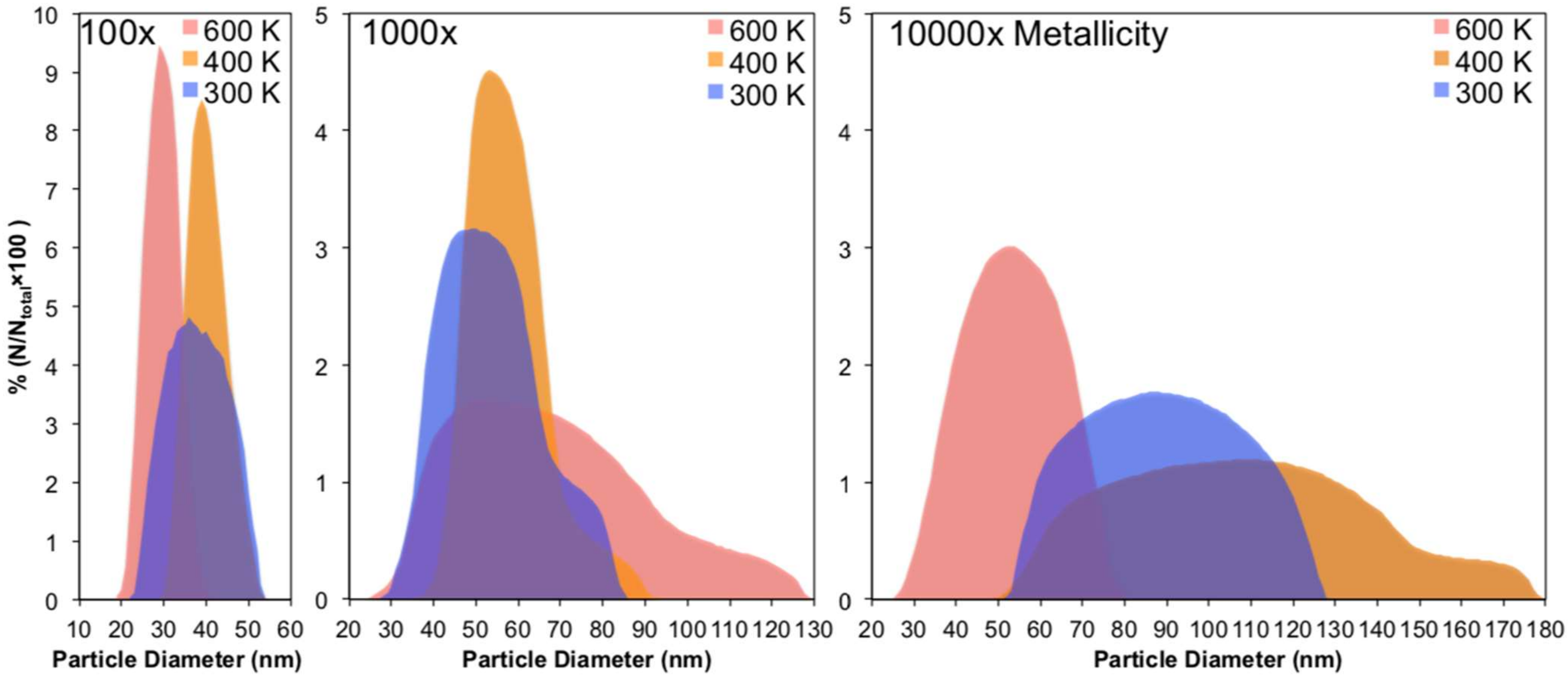

He et al. (2018)

Smaller and/or cooler planets

Marching toward “Earth-like”

Longer orbits → wider distribution of eccentricity, rotation, obliquity

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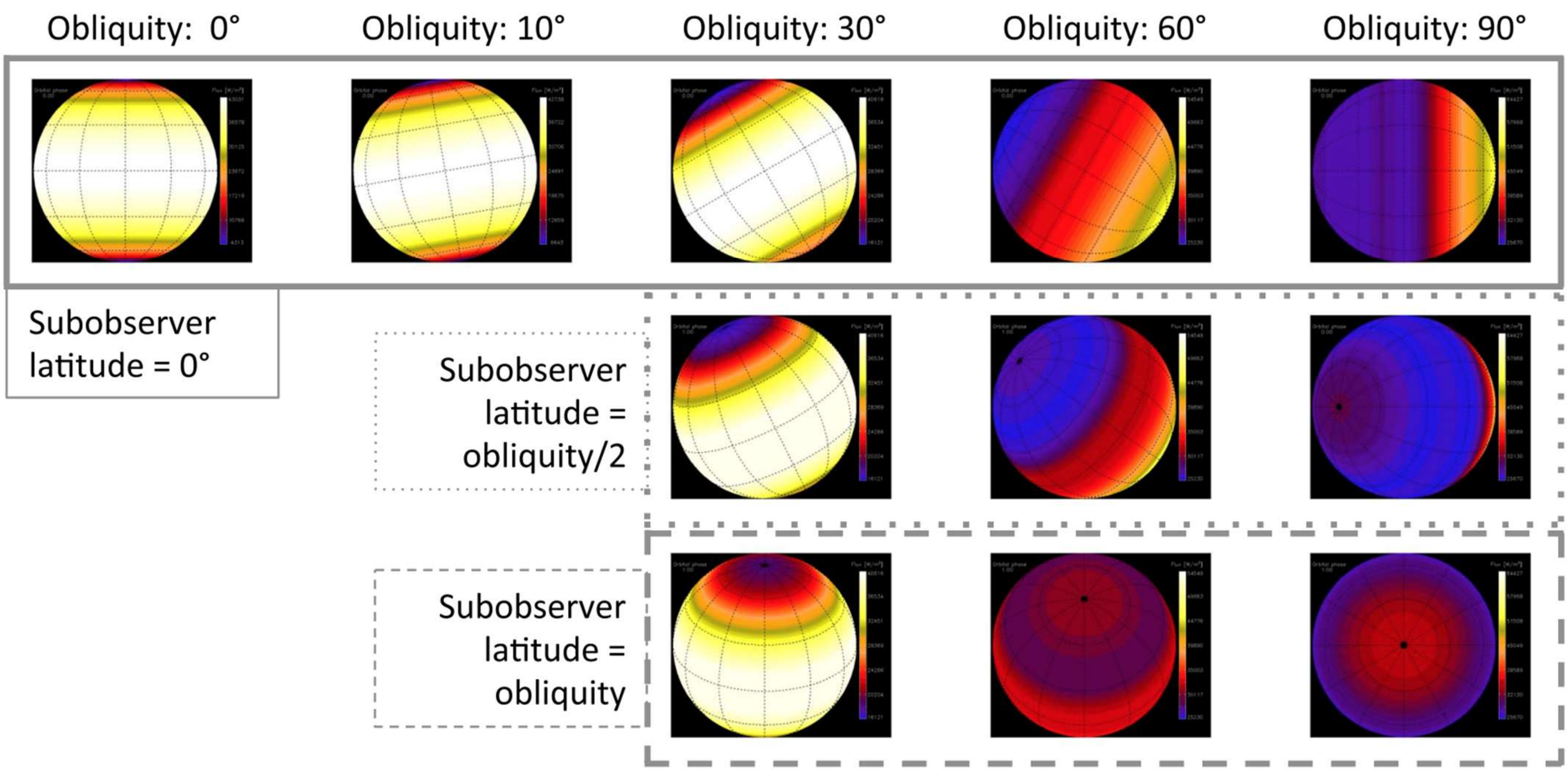
* But maybe hot Jupiters too?

thermal tides: Auclair-Desrotour & LeConte (2018a,b)

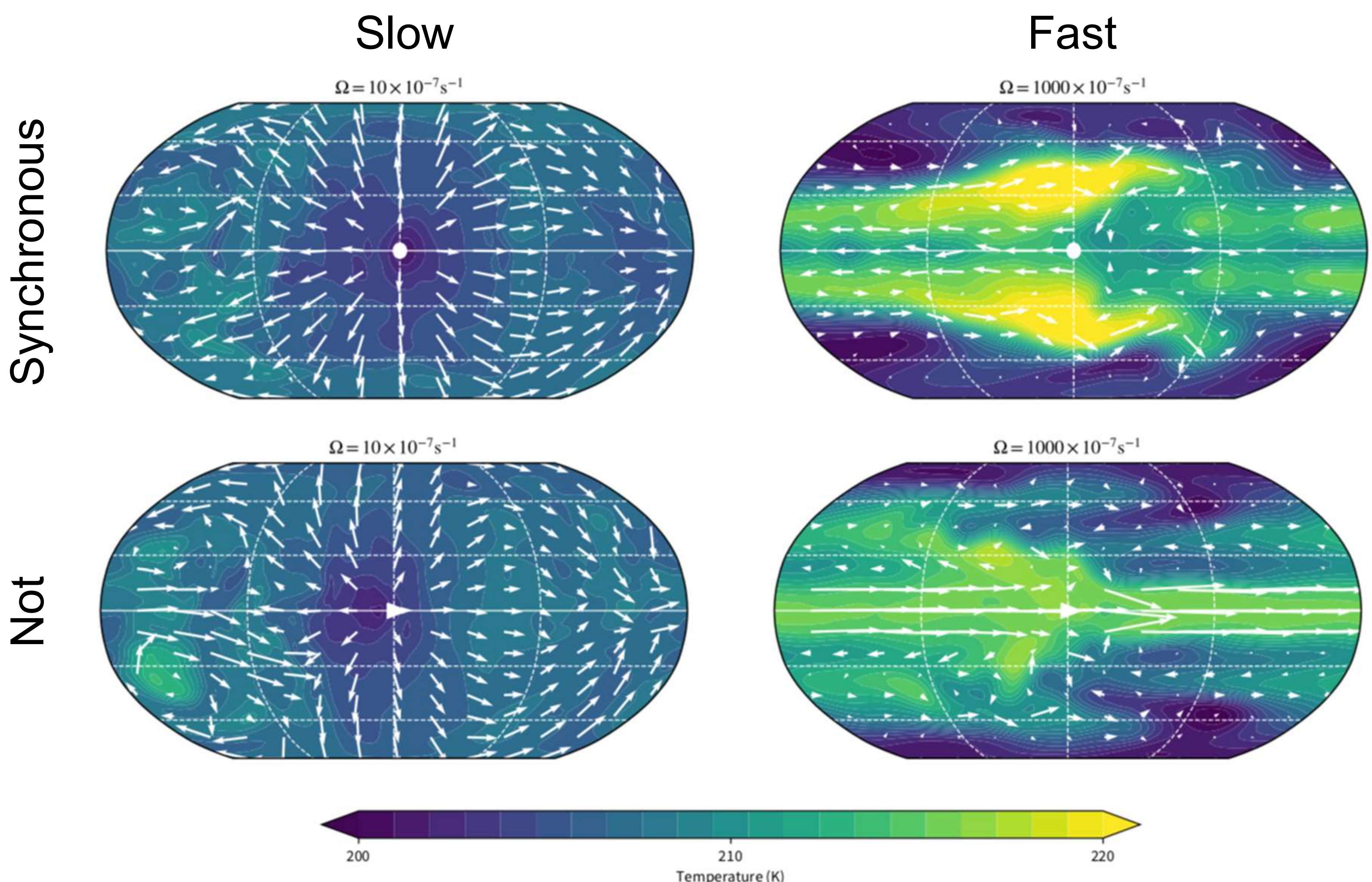
empirical constraints: Flowers et al. (2018)

Obliquities of warm Jupiters



Rauscher (2017)

Rotation and synchronoization of terrestrial planets



Penn & Vallis (2018)

Broad parameter surveys

Around a Sun-like host
(another table for M dwarf host)

Simulation parameters	Global-average T [K]	Eq-pole ΔT [K]	TOA net SW [Wm^{-2}]	TOA net LW [Wm^{-2}]	Albedo
Reference:					
Earth parameters (1 AU)	231.79	139.37	151.72	154.96	0.55
Varying rotation period:					
0.5 days	220.85	128.37	123.29	129.30	0.64
2 days	218.86	109.45	116.61	121.50	0.66
4 days	217.63	97.76	114.74	119.82	0.66
8 days	220.89	93.93	118.13	123.00	0.65
16 days	222.41	75.04	118.96	123.96	0.65
Varying surface pressure:					
0.25 bars	234.89	149.20	164.29	167.07	0.52
0.5 bars	235.19	147.19	162.10	164.44	0.52
2 bars	211.24	96.06	106.43	111.27	0.69
4 bars	211.49	85.36	102.07	108.28	0.70
Varying incident stellar flux:					
0.544 $F_\oplus$ (1.36 AU)	182.42	94.29	58.09	63.04	0.69
0.667 $F_\oplus$ (1.22 AU)	191.93	104.31	70.81	75.68	0.69
0.816 $F_\oplus$ (1.11 AU)	200.81	108.22	86.24	91.02	0.69
1.225 $F_\oplus$ (0.904 AU)	268.85	110.27	225.97	227.70	0.46
Varying planetary radius:					
0.5 $R_\oplus$	239.06	112.42	168.21	171.52	0.51
0.707 $R_\oplus$	216.89	104.15	113.50	118.27	0.67
1.414 $R_\oplus$	236.09	147.65	158.47	161.42	0.53
2 $R_\oplus$	244.65	161.95	171.02	173.62	0.50
Varying surface gravity:					
0.5 $g_\oplus$	236.72	118.03	148.98	152.10	0.56
0.707 $g_\oplus$	232.49	130.18	147.36	151.02	0.57
1.414 $g_\oplus$	231.23	142.14	153.37	156.94	0.55
Varying liquid cloud particle radius:					
7 μm	213.05	110.93	107.31	113.41	0.69
21 μm	239.22	138.15	167.46	170.33	0.51

Komacek & Abbot (2019)

A modeling year in review

- Understanding dynamical regimes
- Ultra-hot Jupiters
- Chemistry
- Clouds
- Smaller and/or cooler planets

- *Feel free to "and a comment" during the Q&A, to promote things I've missed*