Comparative Study

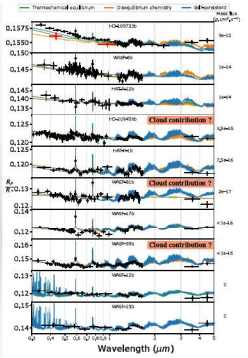
Self-Consistent Model coupling Radiation Field / Thermal structure, Dis-equilibrium Chemistry & Haze Microphysics

Haze significant for Teff < 1400 K

HCN major precursor

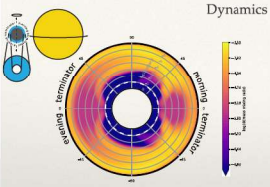
Cloud contributions needed for some cases

Need more precise observations



Arfaux & Lavvas (2022, 2023)

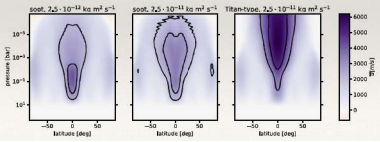
Dynamics



Particles are distributed by the winds.

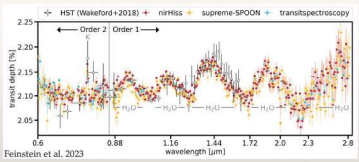
Strong feedback to temperature and dynamics.

Steinrueck et al. 2021,2023



JWST Era

Novel observations instigate / demand more detailed investigations



Feinstein et al. 2023

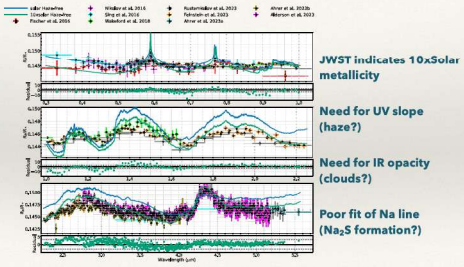
What is the relative contribution of hazes and clouds in the observations?
What is the impact of each component on the atmospheric structure?

WASP-39 b **GJ 1214 b** **TOI-1759 b**

Hot-Jupiters — Warm Neptunes — Temperate Exoplanets

Hot-Jupiters: WASP-39b

Hot-Jupiters: WASP-39 b



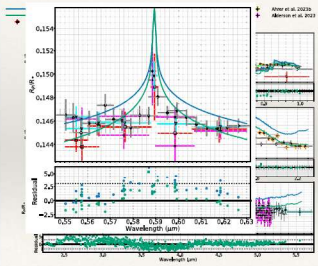
JWST indicates 10xSolar metallicity

Need for UV slope (haze?)

Need for IR opacity (clouds?)

Poor fit of Na line (Na_2S formation?)

Hot-Jupiters: WASP-39 b



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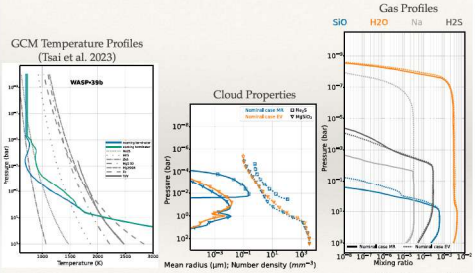

Arfaux & Lavvas 2024

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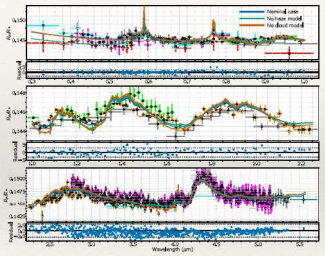

Good fit of Na line (thanks to Na depletion)

Good fit of IR (thanks to Na_2S opacity)

Good fit of UV slope (thanks to haze opacity)

First evidence for hazes & clouds in exoplanet atmosphere

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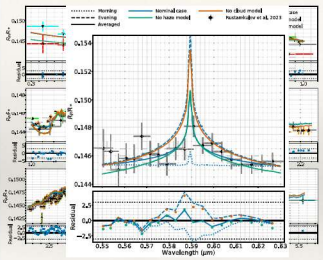

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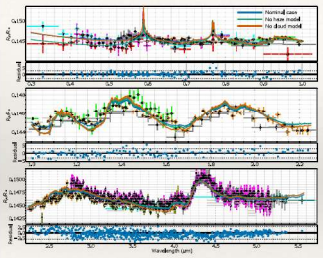

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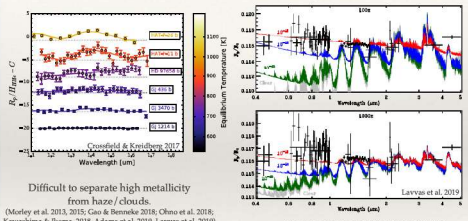
Warm-Neptunes: GJ1214b

Sub-Neptunes

GJ1214b demonstrates the flattest transit spectrum

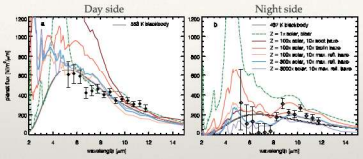


Difficult to separate high metallicity from haze/clouds.

(Morley et al. 2013, 2015; Gao & Benneke 2018; Ohno et al. 2018; Kawashima & Ikoma, 2018, Adams et al. 2019, Lavvas et al. 2019)

Observations: Fraine et al. 2013; Narita et al. 2013; Nascimbeni et al. 2015; Kreidberg et al. 2014

JWST observations

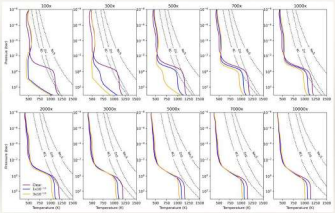


Full phase curve with JWST (Kempton et al. 2023)

From new transit observations Gao et al. 2023 suggested a high mass flux of photochemical hazes.

Can new constraints from emission and eclipse improve the characterisation of GJ1214 b ?

Temperature Profiles
(with dis-equilibrium chemistry and haze / cloud opacity)



100x - 10 000x Solar Metallicity cases

Clear

$1x10^{-11}$ g cm^{-2}s^{-1}

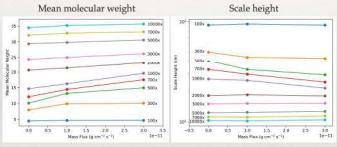
$3x10^{-11}$ g cm^{-2}s^{-1}

Haze cools the lower atmosphere, affecting the lower boundary conditions, i.e. the atmospheric composition

This has further ramifications for the mean molecular weight and the scale height of the atmosphere

Temperature Profiles
(with dis-equilibrium chemistry and haze / cloud opacity)

Mean molecular weight



Scale height

Haze impact for 300x-3000x solar metallicity

100x - 10 000x Solar Metallicity cases

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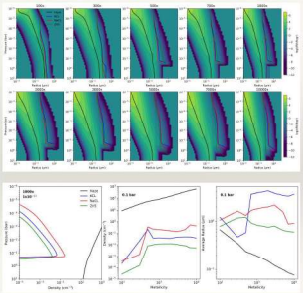
Particle Size Distribution



Metallicity affects the haze and cloud properties through changes in temperature, abundance and settling velocity of the particles

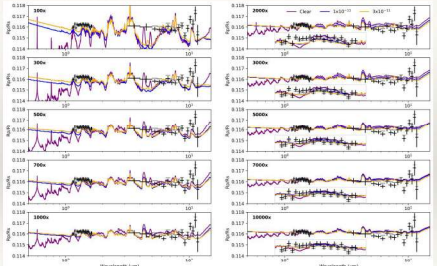
For haze increasing metallicity decreases the average particle size.

For clouds metallicity trends depend on the cloud type and the conditions of formation.

Haze radius: 0.7 - 0.07 μm
Cloud radius: 0.5 - 5 μm

Warm Neptunes: GJ 1214 b

Transit



Observations from Fraine et al. 2013, Kreidberg et al. 2014, Kempton et al. 2023