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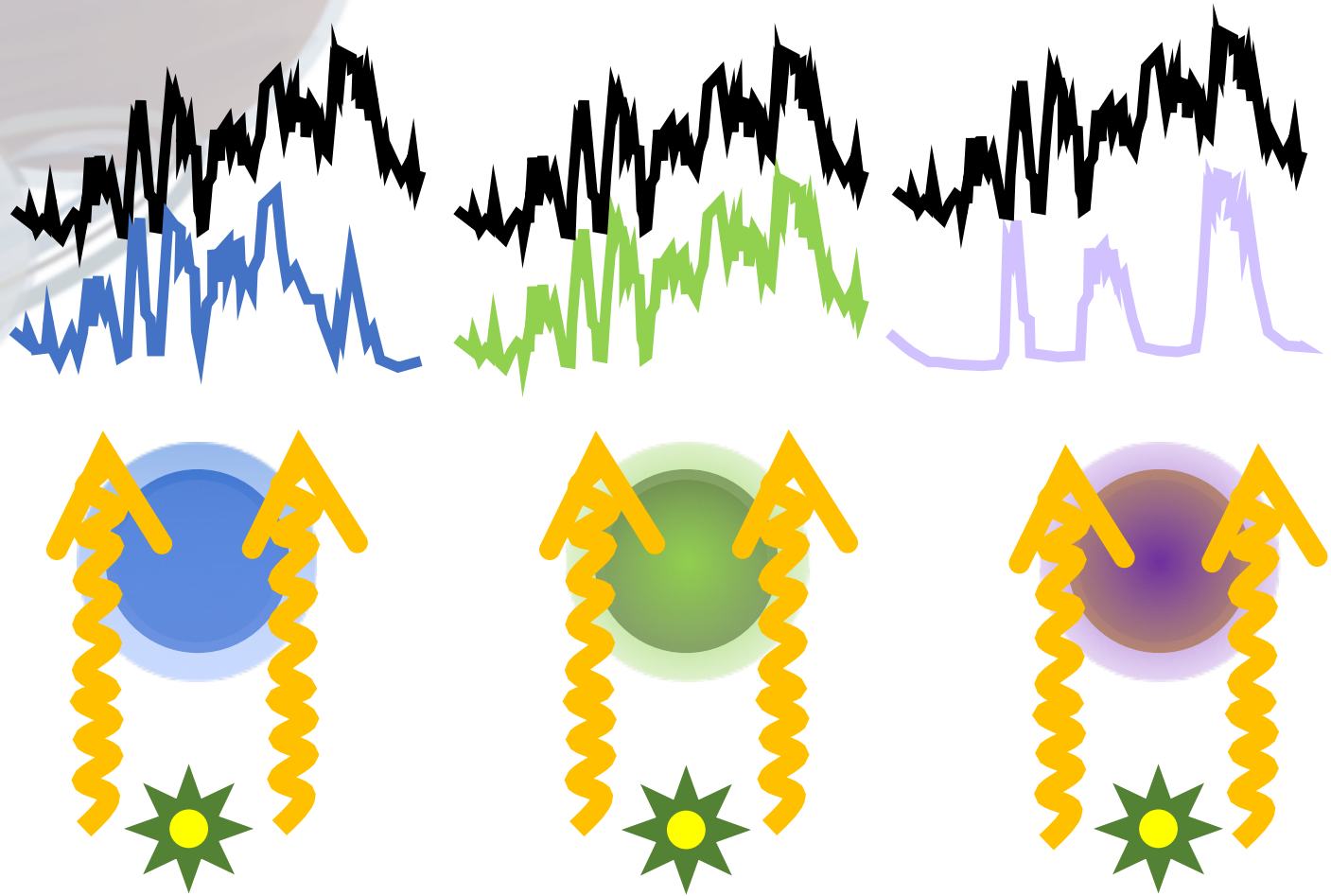
Retrieval Comparison:
Benchmarking with NEMESIS, TauREX and CHIMERA

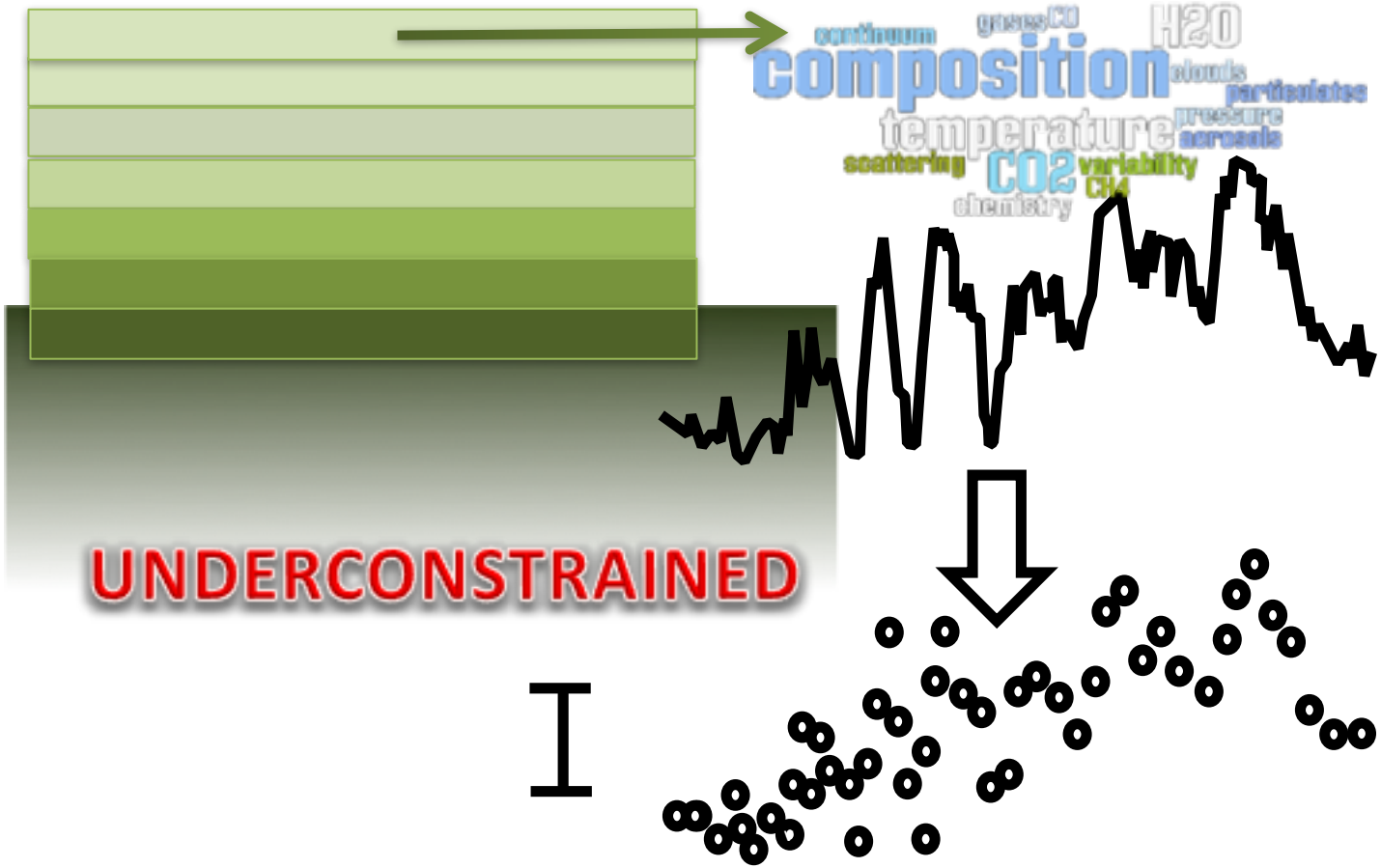
Joanna Barstow (RAS Research Fellow)[1],
Ryan Garland[2], Mike Line[3], Marco Rocchetto[1] & Ingo Waldmann[1]

[1]UCL, London, UK; [2]University of Oxford, Oxford, UK; [3]School of Earth and Space Exploration, Arizona State University, AZ, USA

Spectral retrieval – how it works

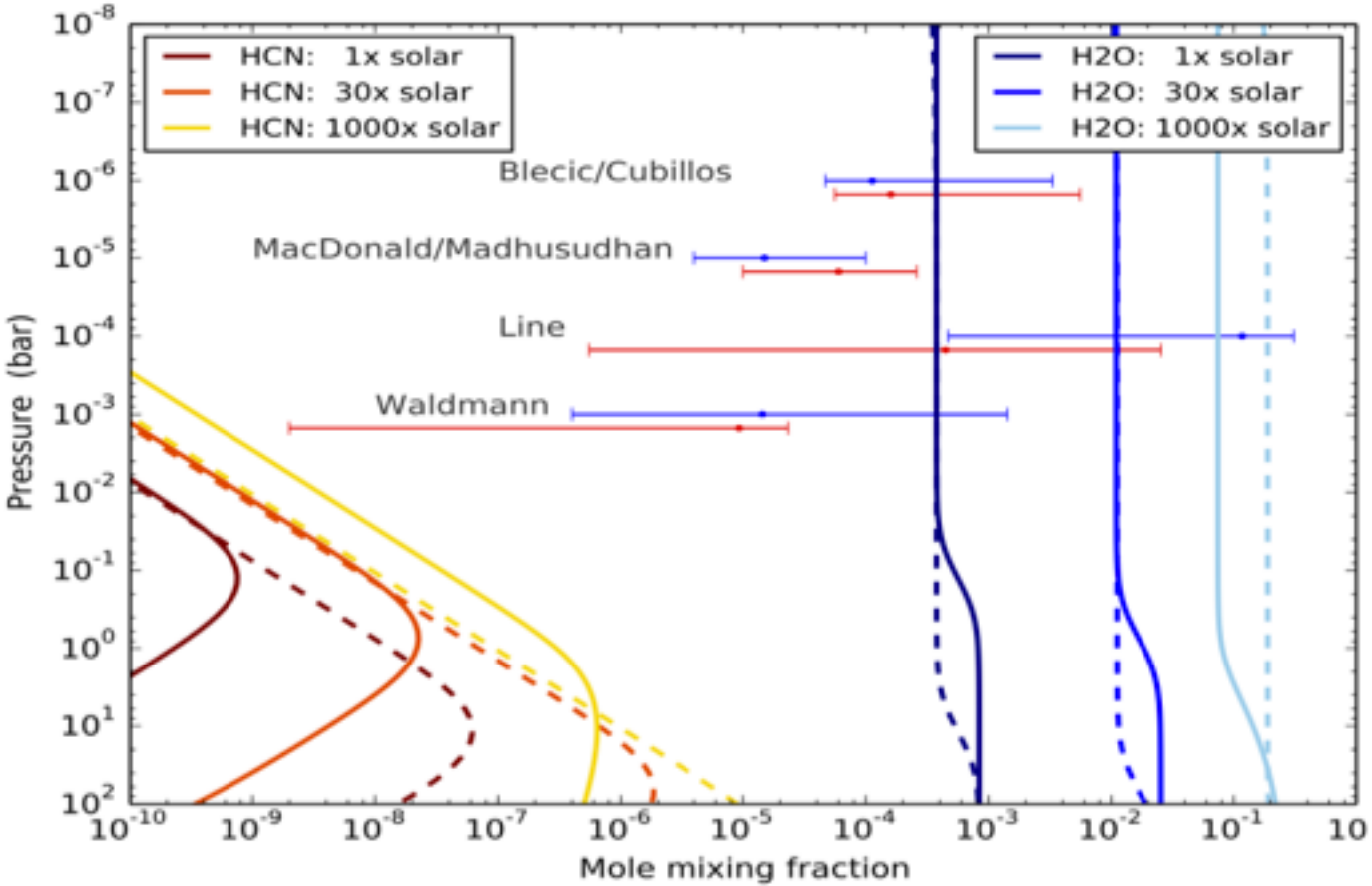


Spectral retrieval – how it works REALLY



Retrieval comparison – why?

- Several different forward models/algorithms used by different groups to interpret exoplanet spectra
- They don't always give the same answer when applied to the same datasets – see e.g. Kilpatrick et al. 2017
- All contain simplifications/parameterizations – no such thing as a perfect model
- Important to understand origins of differences, and make sure that when *the same assumptions are made the same result is obtained*.



Kilpatrick et al. 2017

arxiv.org/abs/1704.07421

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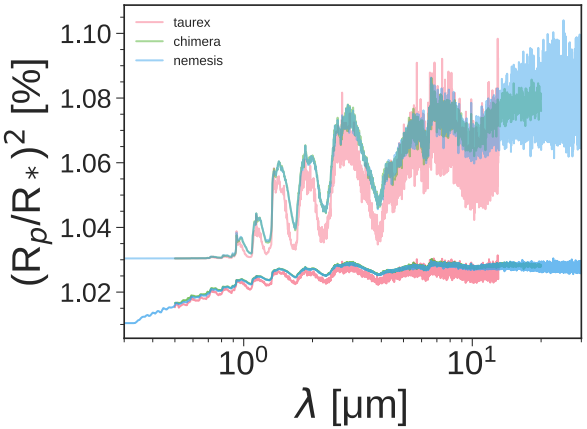
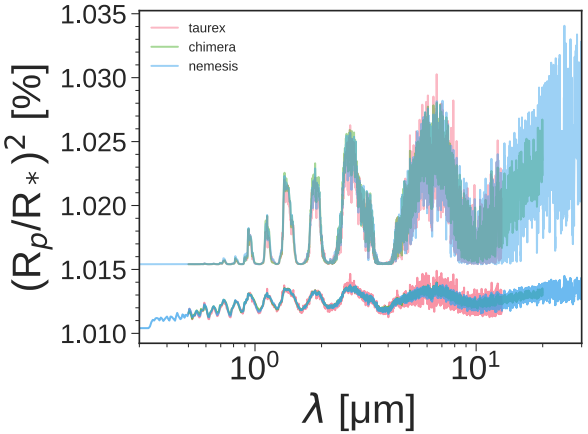
Retrieval comparison – what?

- Initial check – do forward models produce the same spectra for the same input parameters?
- Then, cross-retrieve: does a retrieval with one code correctly identify the inputs for a synthetic observation generated by another code?
- 3 codes: NEMESIS (Irwin et al. 2008), TauREX (Waldmann et al. 2015) and CHIMERA (Line et al. 2013). NEMESIS originally Solar System (see Pat Irwin's talk later today), TauREX and CHIMERA both developed for exoplanets.
- Retrieval algorithm for all 3 is MultiNest (Feroz et al. 2009)

Single species models – H_2O

- First test – single trace species, no clouds or collision-induced absorption.
- Plots show results for 2000 K (left), 500 K (right), 1 ppmv (top) and 100% (bottom). Rest of atmosphere has mean molecular weight of 2.3 (solar composition H_2-He mix)





Single species models – CO_2

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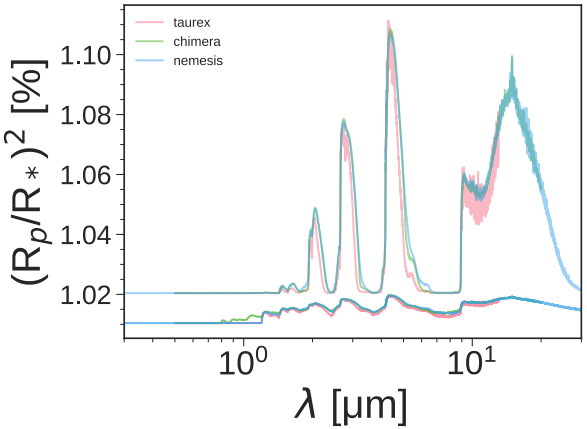

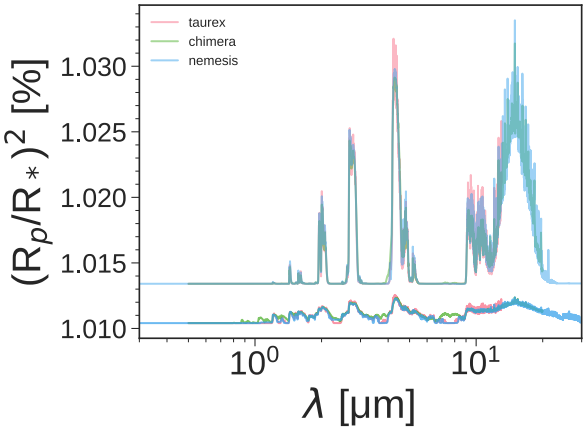

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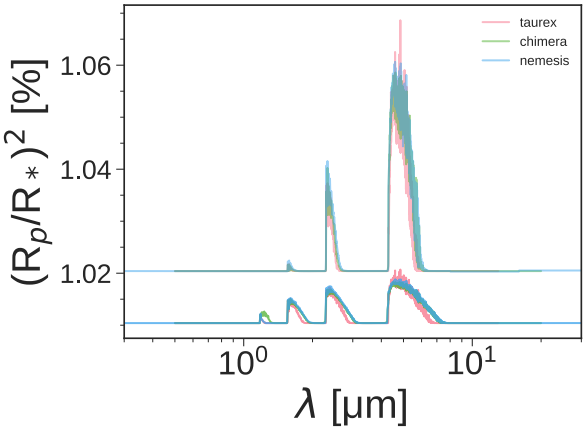

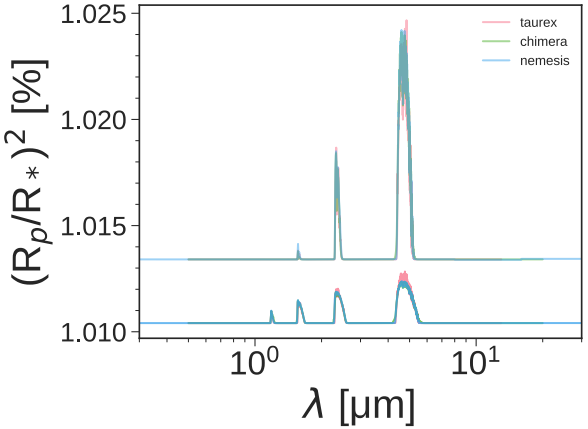

Single species models – CH_4

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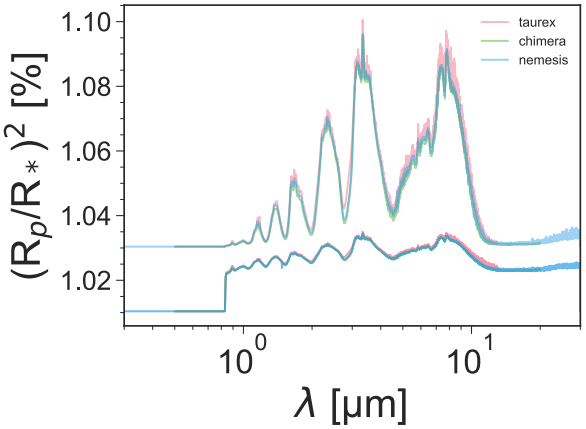

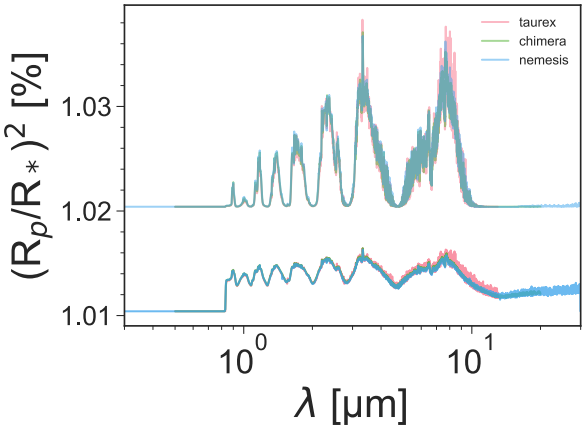

Single species models – NH_3

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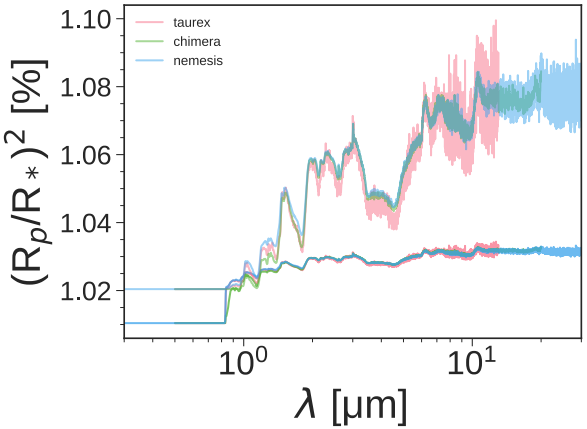
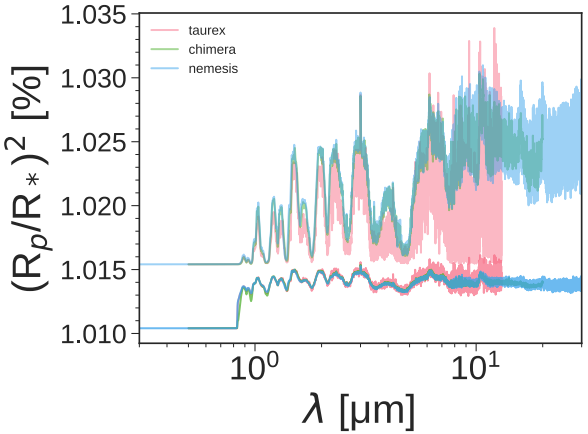
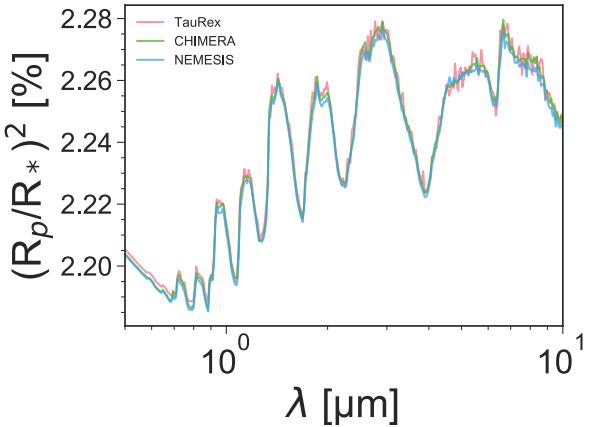
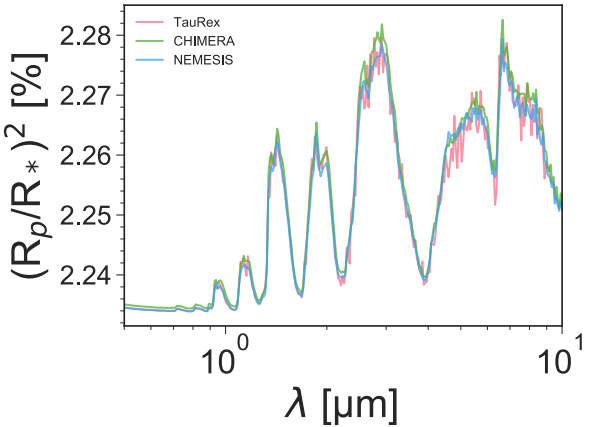




More complex hot Jupiters

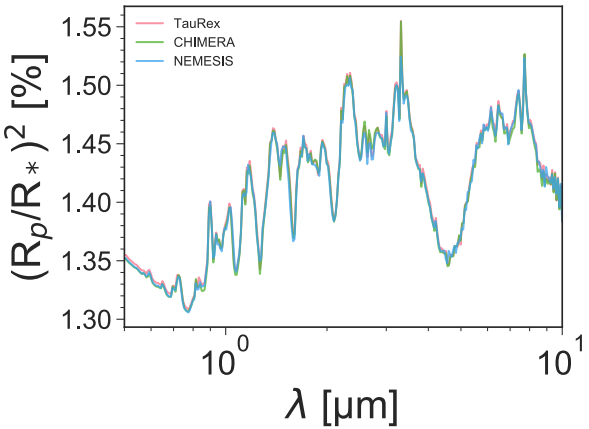
- Second test – introduce planets with combinations of gases, collision-induced absorption and clouds
- Hot Jupiter – bulk properties same as HD 189733b. Composition: 300 ppmv H_2O, 350 ppmv CO. Left: cloud-free. Right: opaque, grey cloud at 10 mbar

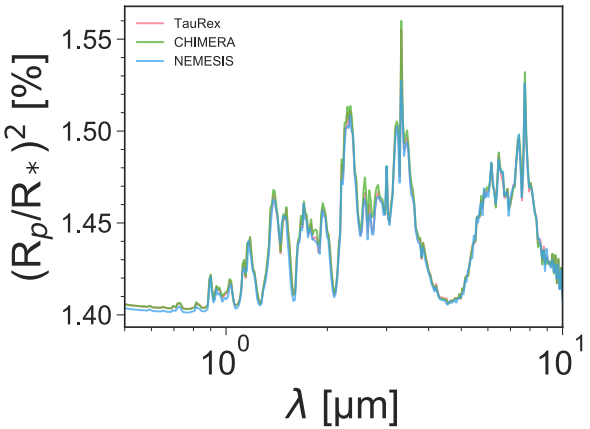


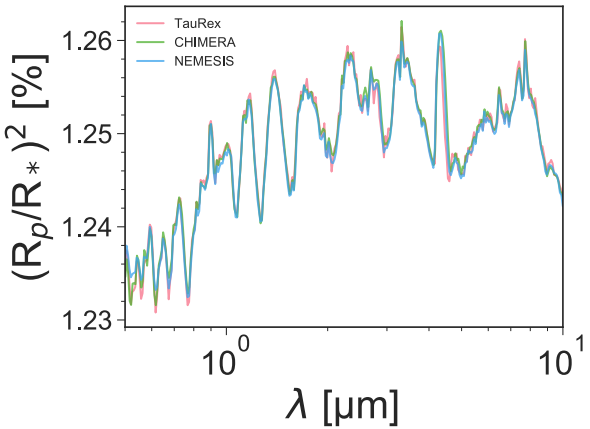


More complex super Earths

- Super Earth – bulk properties same as GJ 1214b. Composition: 800 ppmv H_2O, 400 ppmv CH_4, 100 ppmv NH_3. Left: cloud-free. Middle: opaque, grey cloud at 10 mbar.
- Right: high MMW – composition 0.43 H_2O, 0.25 CO_2, 0.14 CH_4, 0.13 N_2 (no collision-induced absorption)

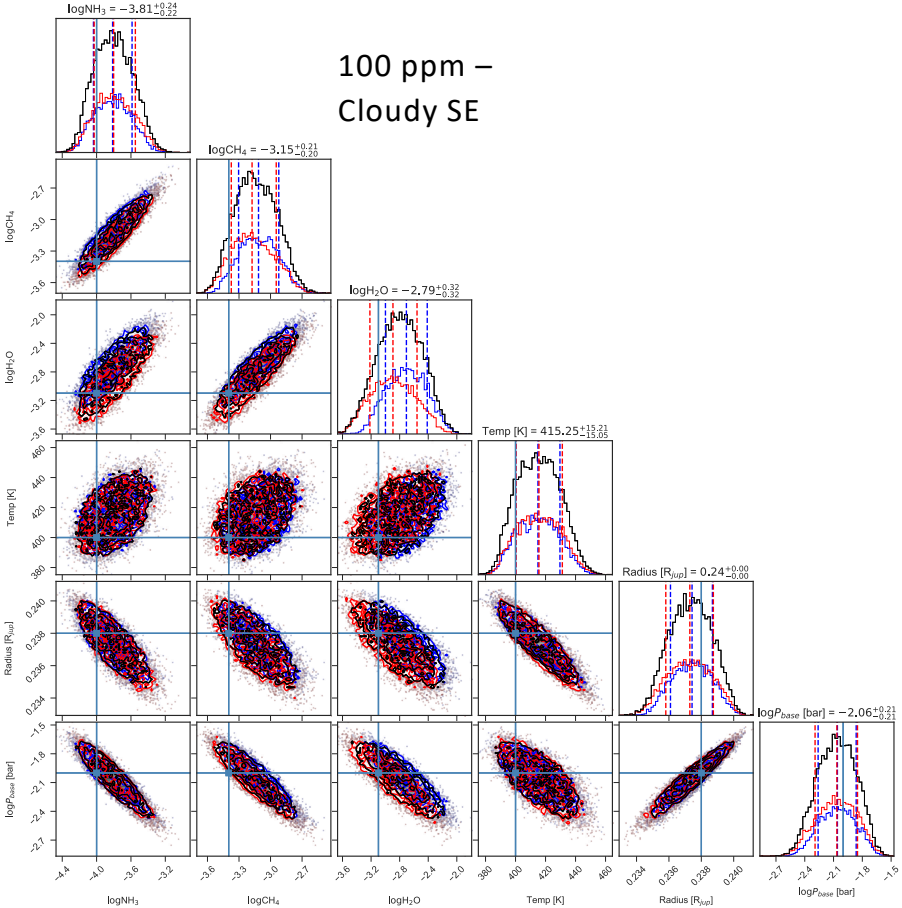




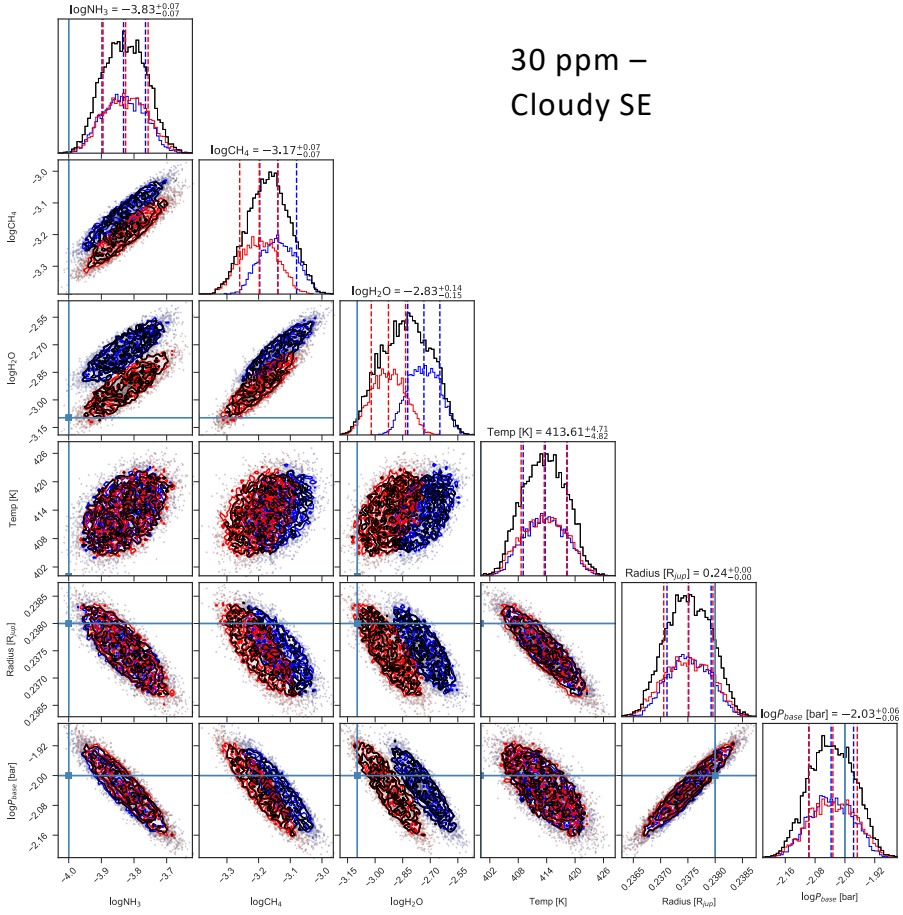


Cross retrieval: NEMESIS

100 ppm –
Cloudy SE

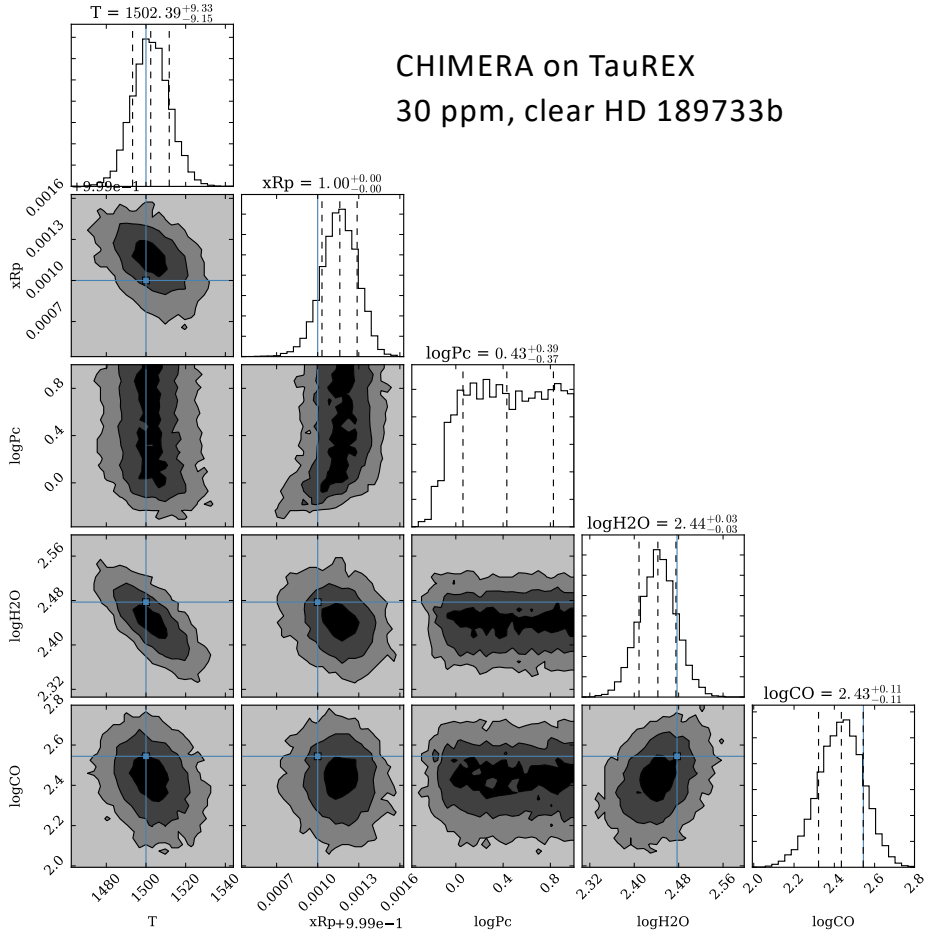


30 ppm –
Cloudy SE

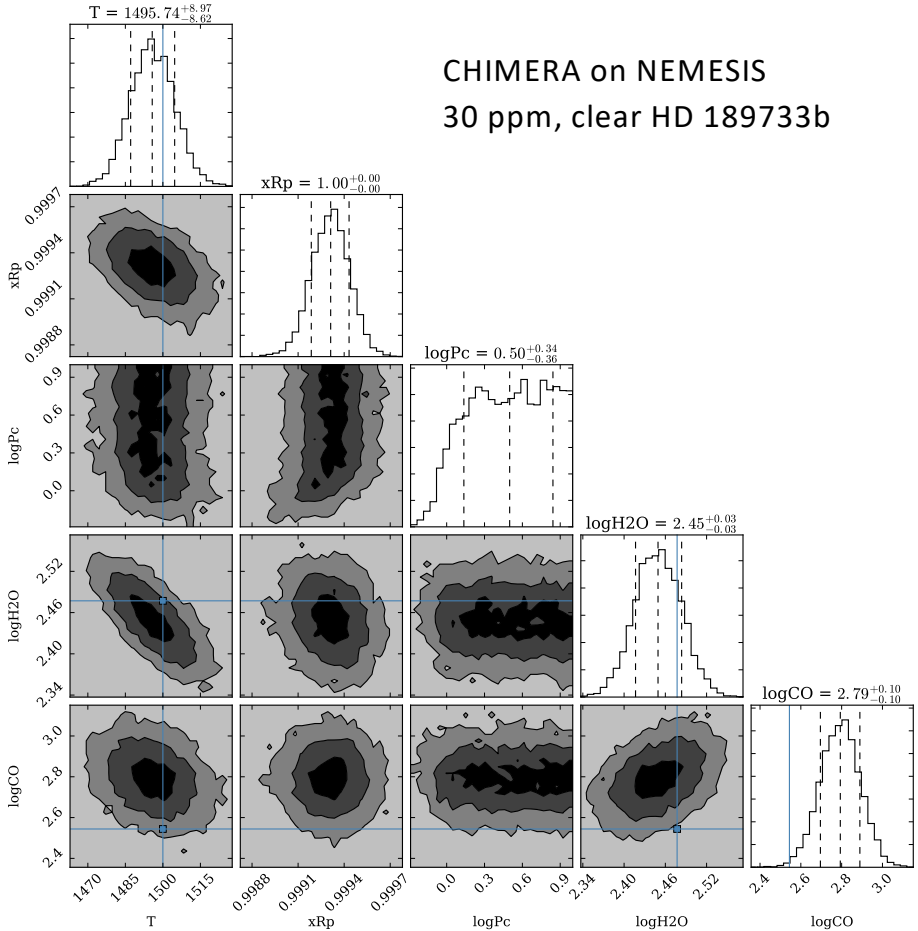


Blue = CHIMERA, Red = TauREX

Cross retrieval: CHIMERA

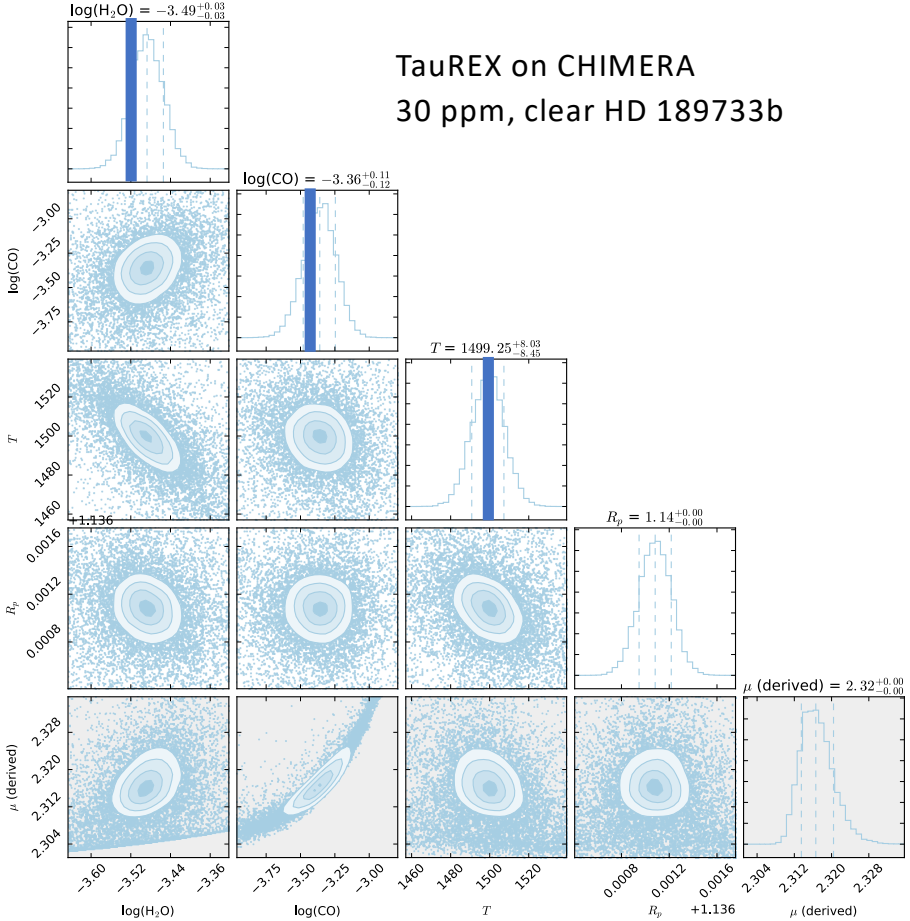


CHIMERA on TauREX
30 ppm, clear HD 189733b

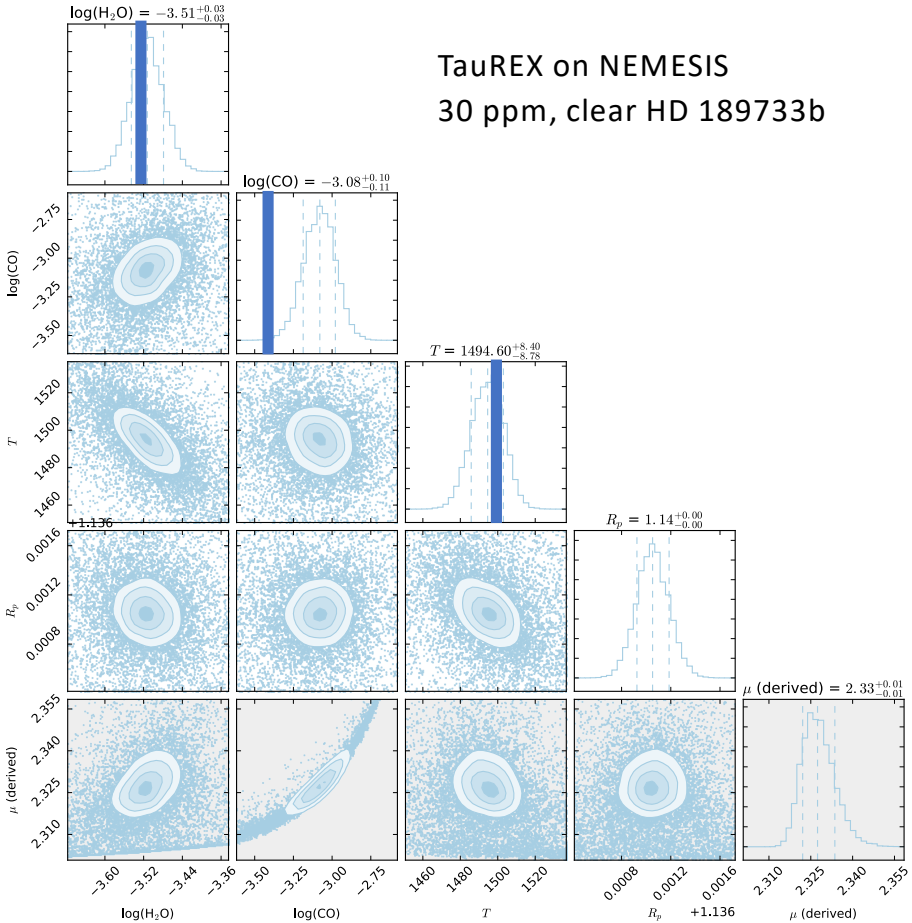


CHIMERA on NEMESIS
30 ppm, clear HD 189733b

Cross retrieval: TauREX



TauREX on CHIMERA
30 ppm, clear HD 189733b



TauREX on NEMESIS
30 ppm, clear HD 189733b

Retrieval comparison: conclusions so far

- Comparison is not perfect – with small error bars, what look like tiny differences between the forward models make a difference to the retrieval
- This will have an effect when dealing with real data – it's particularly important to be careful with systematic noise (astrophysical or instrumental)
- Multiple retrieval codes are a good thing! Differences in the answers can be informative provided we understand where they come from.