First results from the ESO SupJup Survey

Detection of chemical dis-equilibrium in brown dwarf DENIS J0255's atmosphere

Sam de Regt
Leiden Observatory
regt@strw.leidenuniv.nl

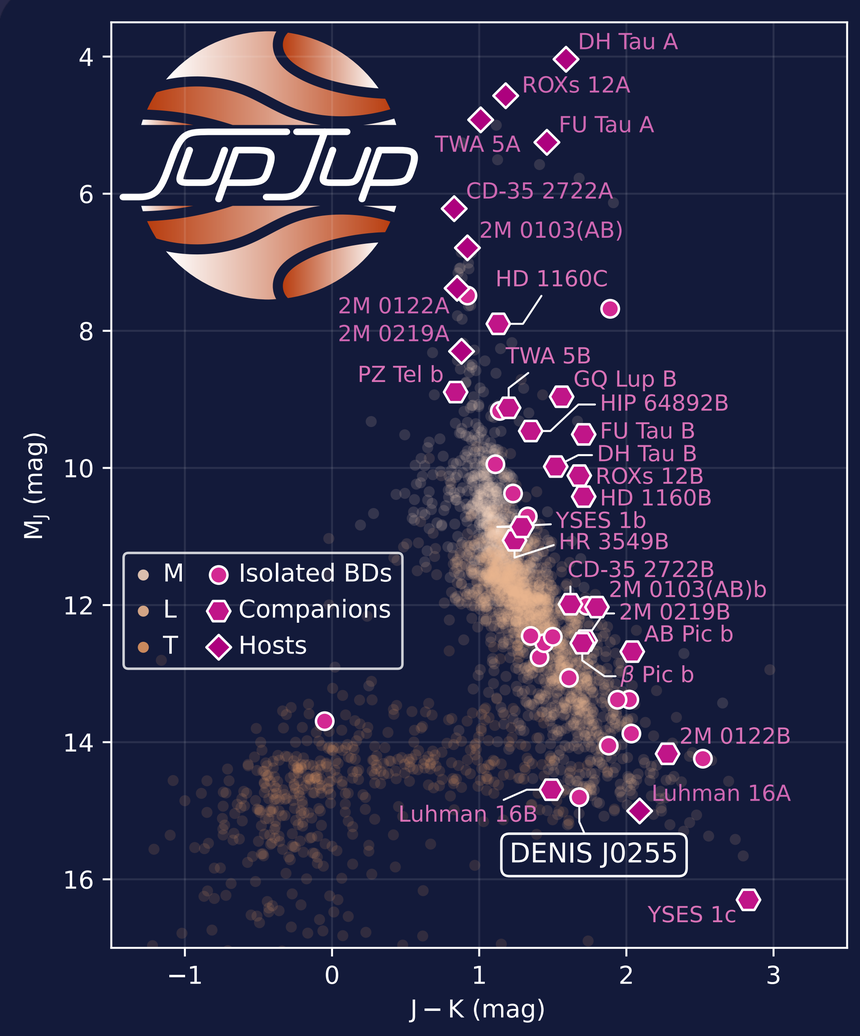


Fig. 1: Colour-magnitude diagram of the targets observed as part of the ESO SupJup Survey.

Introduction

The ESO SupJup Survey is aimed at disentangling the formation pathways of a sample of Super-Jupiters, free-floating planets and brown dwarfs. Combining the C/O ratio, metallicity and $^{12}C/^{13}C$ isotope ratio can help to identify formation processes within the protoplanetary disk[1]. Additionally, isotopic diversity could be a sign of distinct formation mechanisms between isolated brown dwarf and exoplanets[2].

The survey was carried out with the recently upgraded VLT/CRIRES$^+$ spectrograph. A diverse sample of 19 isolated objects, 19 companions and 11 hosts were observed at high spectral resolution in the K-band (Fig. 1)

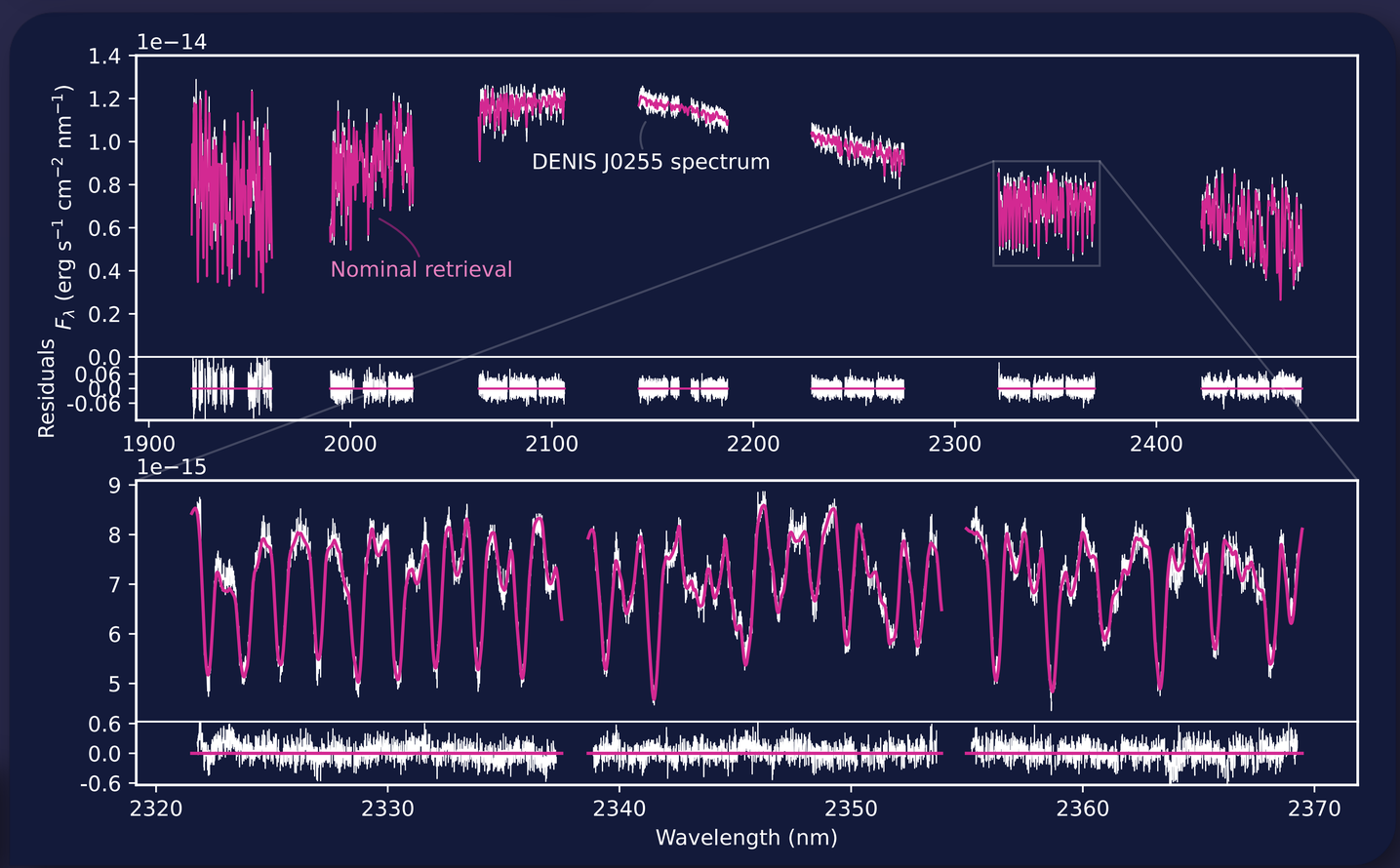


Fig. 2: Best-fitting model to the observed spectrum of DENIS J0255

Retrieval of DENIS J0255

The spectrum observed for the L9-dwarf DENIS J0255 can help in understanding the origin of the L-T transition.

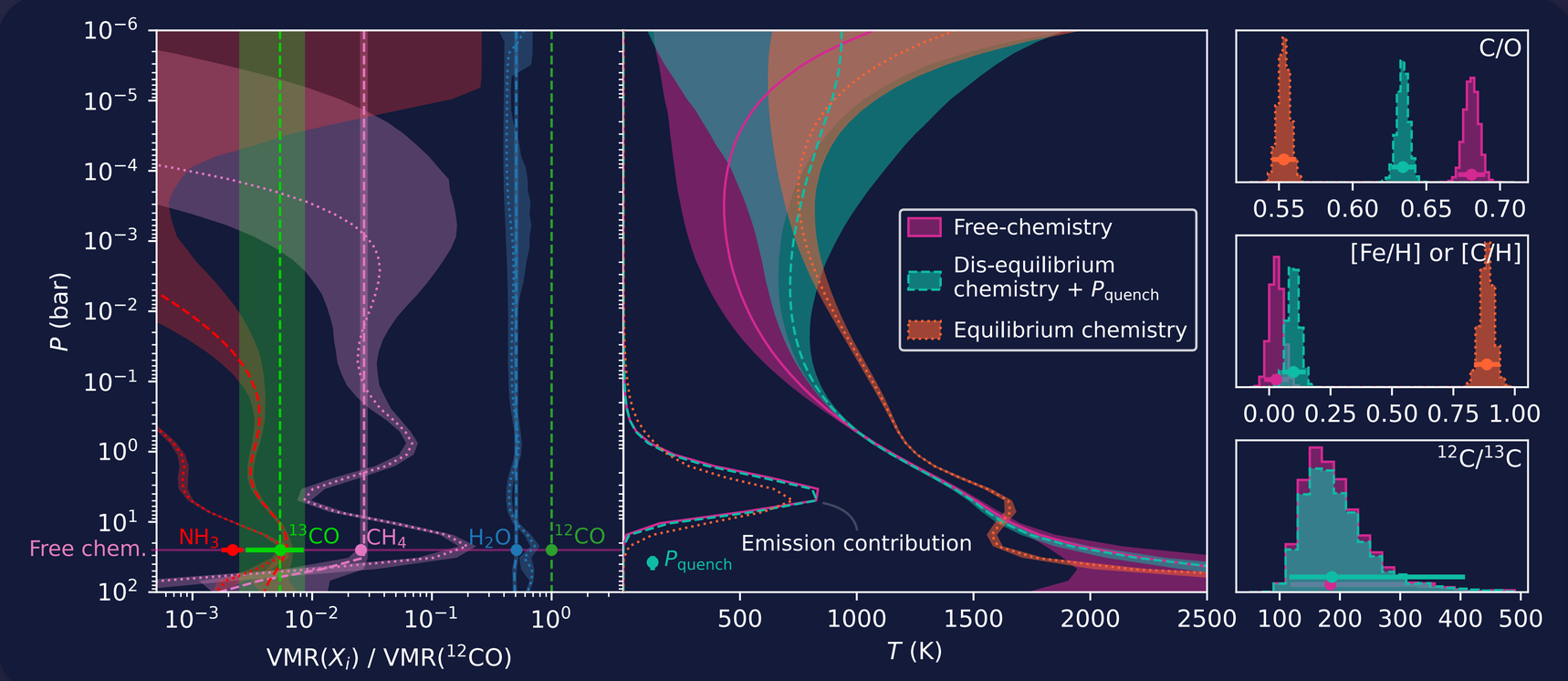
Atmospheric retrievals are carried out with PyMultiNest and the radiative transfer code petitRADTRANS (pRT). The PT-profile is constructed via spline interpolation through 7 temperature knots. Pixel-correlation is modelled with Gaussian Processes.

The nominal model uses a free-chemistry approach, but retrievals were also performed with pRT's chemical equilibrium implementation, both with and without quenching of the CO, CH_4 and H_2O abundances.

Results and Conclusions

The nominal model provides an excellent fit of the observed spectrum (Fig. 2). The PT-profile (Fig.3: pink/solid) is nearly identical to that found by the quenched dis-equilibrium retrieval (green/dashed). The retrieved abundances (relative to ^{12}CO) are also extremely similar. The un-quenched equilibrium chemistry retrieval (orange/dotted) is strongly disfavoured (>10σ). In equilibrium, the PT-profile, metallicity and C/O ratio are altered to reduce the photospheric CH_4 abundance. Since none of the retrievals find a grey cloud solution, these dis-equilibrium results appear to support chemical instability as an explanation for the reddened colour of DENIS J0255[3].

The NH_3 and ^{13}CO abundances are constrained and their inclusion is favoured by 7.9σ and 2.7σ, respectively. The resulting isotope ratio is $^{12}C/^{13}C = 184^{+175}_{-67}$, indicating a ^{13}C-depletion compared to the local ISM (~68), akin to earlier work for the young brown dwarf 2M 0355 (108^{+10}_{-10})[2,4]. Future work will assess whether this is a recurrent result.



Retrieval set-up	ΔIn(Z)	"sigma"
Nominal retrieval	-	-
Dis-eq. chem. (P_{quench})	−4.94	3.6 σ
Eq. chem.	−415.9	> 10 σ
Nominal w/o CH_4	−263.3	> 10 σ
Nominal w/o NH_3	−29.12	7.9 σ
Nominal w/o ^{13}CO	−2.45	2.7 σ
HITEMP H_2O line list	−315.0	> 10 σ

Fig. 3: Chemical and thermal properties found with 3 retrieval set-ups: free-, equilibrium-, and quenched dis-equilibrium chemistry. Errorbars and envelopes show the 95% confidence intervals.

References: [1] Zhang, Y., Snellen, I. A. G., Bohn, A. J. et al. 2021a, Nature, 595, 370
[2] Zhang, Y., Snellen, I. A. G., & Mollière, P. 2021b, A&A, 656, A76
[3] Tremblin, P., Amundsen, D. S., Chabrier, G. et al. 2016, ApJL, L19, 817
[4] Zhang, Y., Snellen, I. A. G., Brogi, M., & Birkby, J. L. 2022, RNAAS, 6, 194