Directly imaged exoplanets in reflected starlight: The importance of knowing the planet radius

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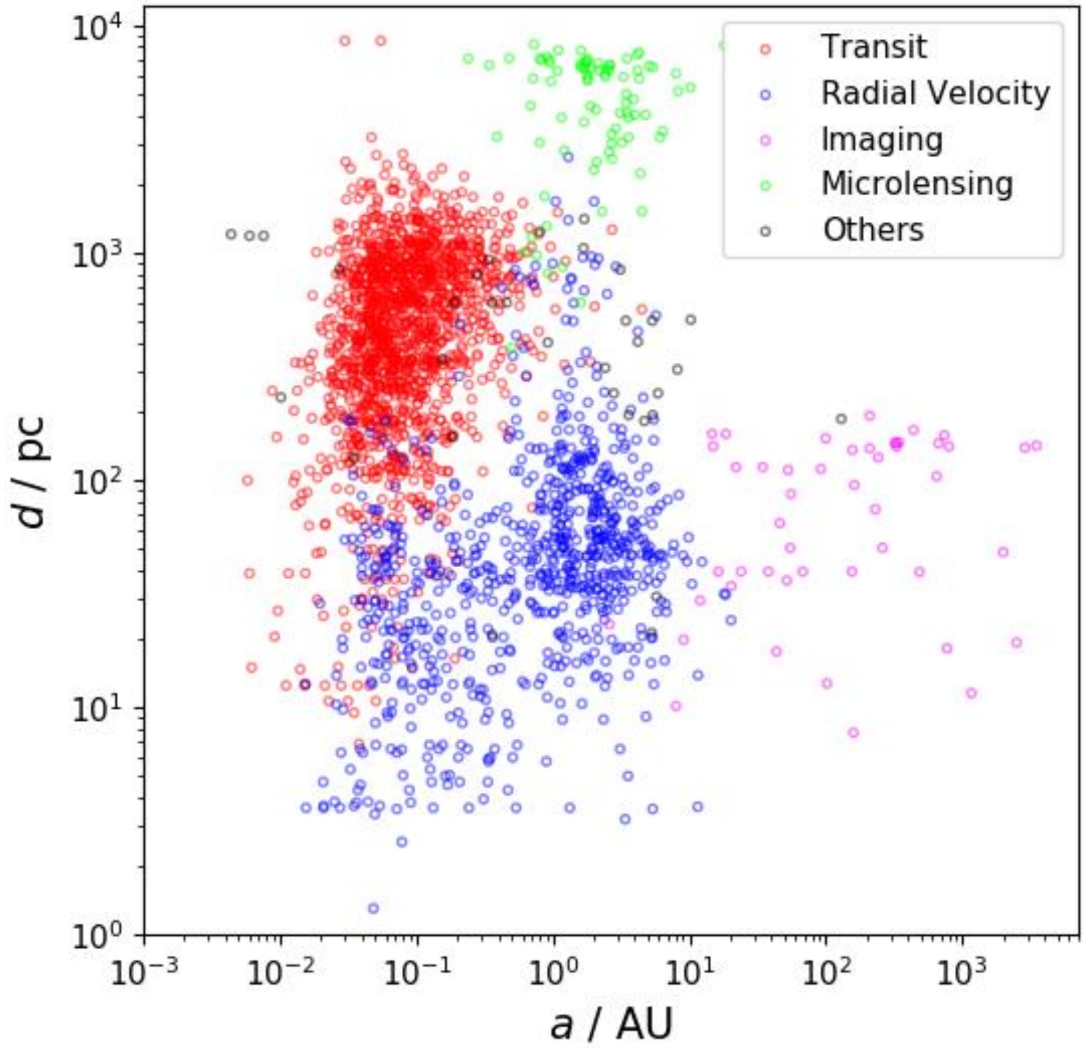
Direct-imaging will be a key technique to characterize the atmospheres of non-transiting exoplanets. Space telescopes using this method are planned to be launched in this decade and several works are trying to predict their science outcome through retrieval exercises.

Here we present an atmospheric model and a retrieval package that we developed to study how different planet and atmospheric parameters affect the reflected-light spectra that will be measured. We find that our knowledge of the planet radius will play a major role in the atmospheric characterization. For instance, if the value of the planet radius (R_p) is unknown, it will be challenging to distinguish between cloudy and cloud-free atmospheres.

We therefore conclude that R_p, a parameter which was not considered in previous studies of direct-imaging observations, should be included in future retrieval exercises of this type.

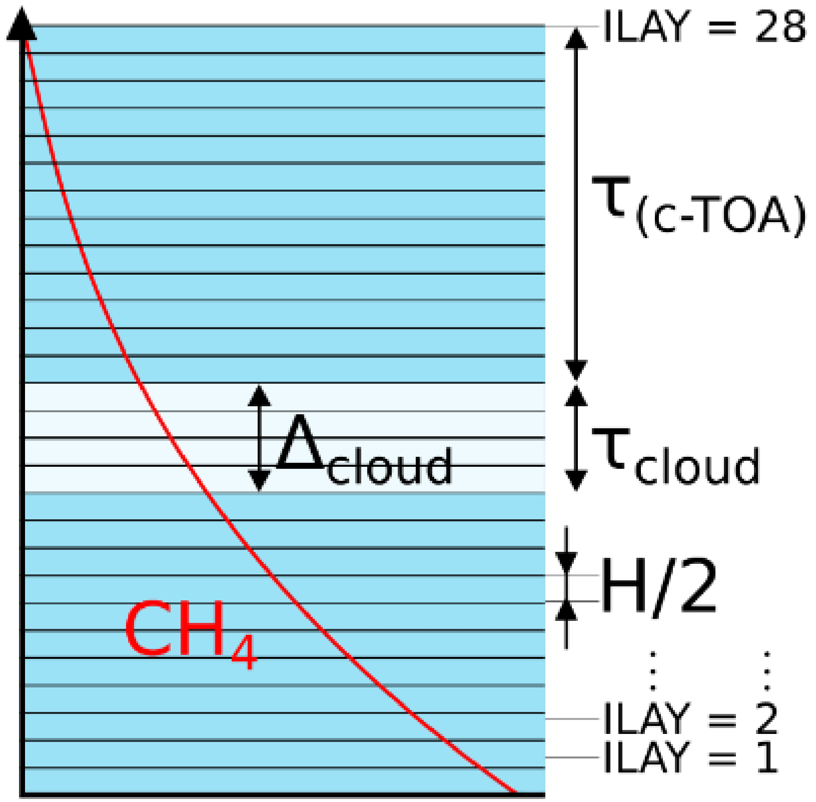
Context

- More than 4100 exoplanets have been confirmed.
- Exoplanets are mainly detected in transit and this technique is more sensitive to short-period planets.
  - The exoplanet population is biased towards hot planets in close-in orbits.
- Exoplanetary atmospheres are currently characterized with transit spectroscopy.
  - Generally, exoplanets in long-period orbits will not be observable.
  - Even if some long-period planets are found to transit, light refraction will limit our measurements to the upper atmospheric layers.
- To analyse the population of cold and temperate exoplanets and their atmospheres, direct-imaging observations will be needed.



Description of the work

Atmospheric model



General description of H_2-He-dominated atmospheres. We include CH_4 as the only gaseous absorbing species and a cloud layer.

Synthetic spectra

The reflected-light spectra are computed by solving the multiple-scattering radiative transfer problem with a previously-validated code(*).

- The wavelength range is 500-900 nm
- The spectral resolution, R~125-225

(*)García Muñoz & Mills (2015)

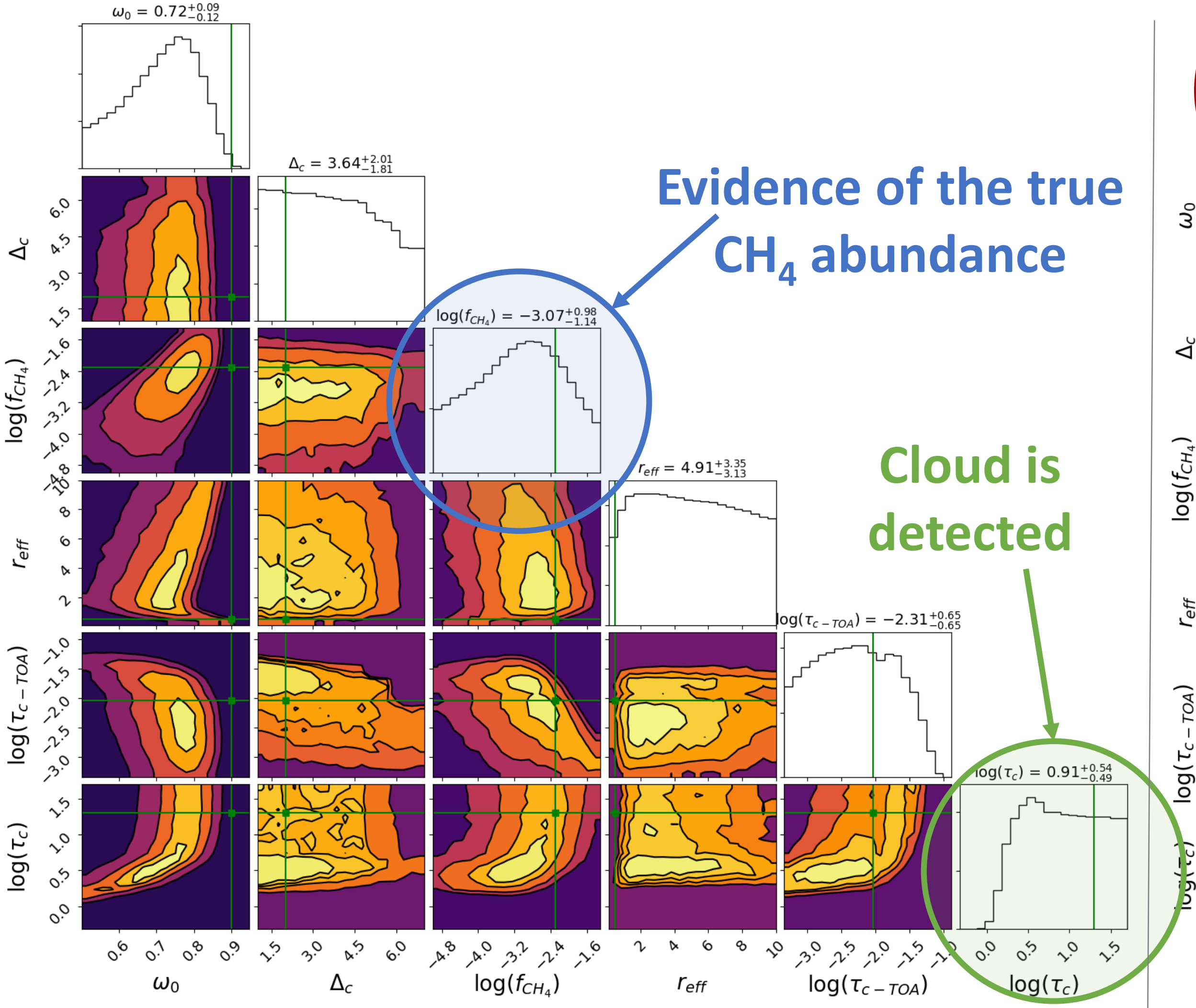
Retrieval package

We simulate a measurement by adding noise (S/N=10) to a certain spectrum corresponding to the assumed *true* atmospheric configuration (which would be a priori unknown for the observer).

Then, we sample the space of parameters with the MCMC sampler *emcee*. With χ^2 figure of merit, we compute those regions of the parameter space where the probability of finding the *true* atmospheric configuration is higher.

Results

Retrievals for a *thick-cloud* scenario. That is, the *true* atmospheric configuration (green lines in the plots) includes a cloud layer with optical thickness **τ_c=20**.

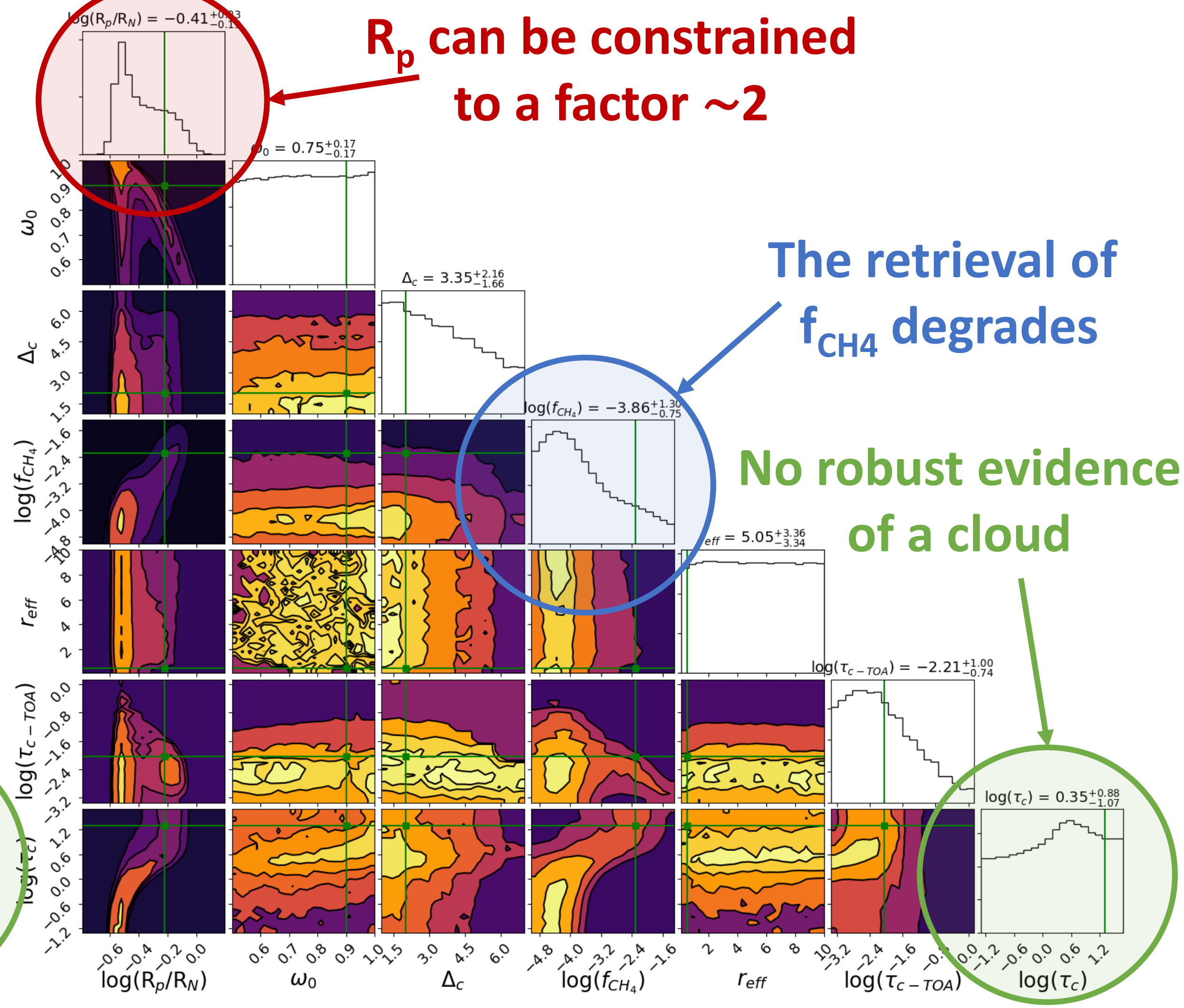


Evidence of the true CH_4 abundance

Cloud is detected

R_p known

(6D param. space)



R_p can be constrained to a factor ~2

The retrieval of f_{CH4} degrades

No robust evidence of a cloud

R_p unknown

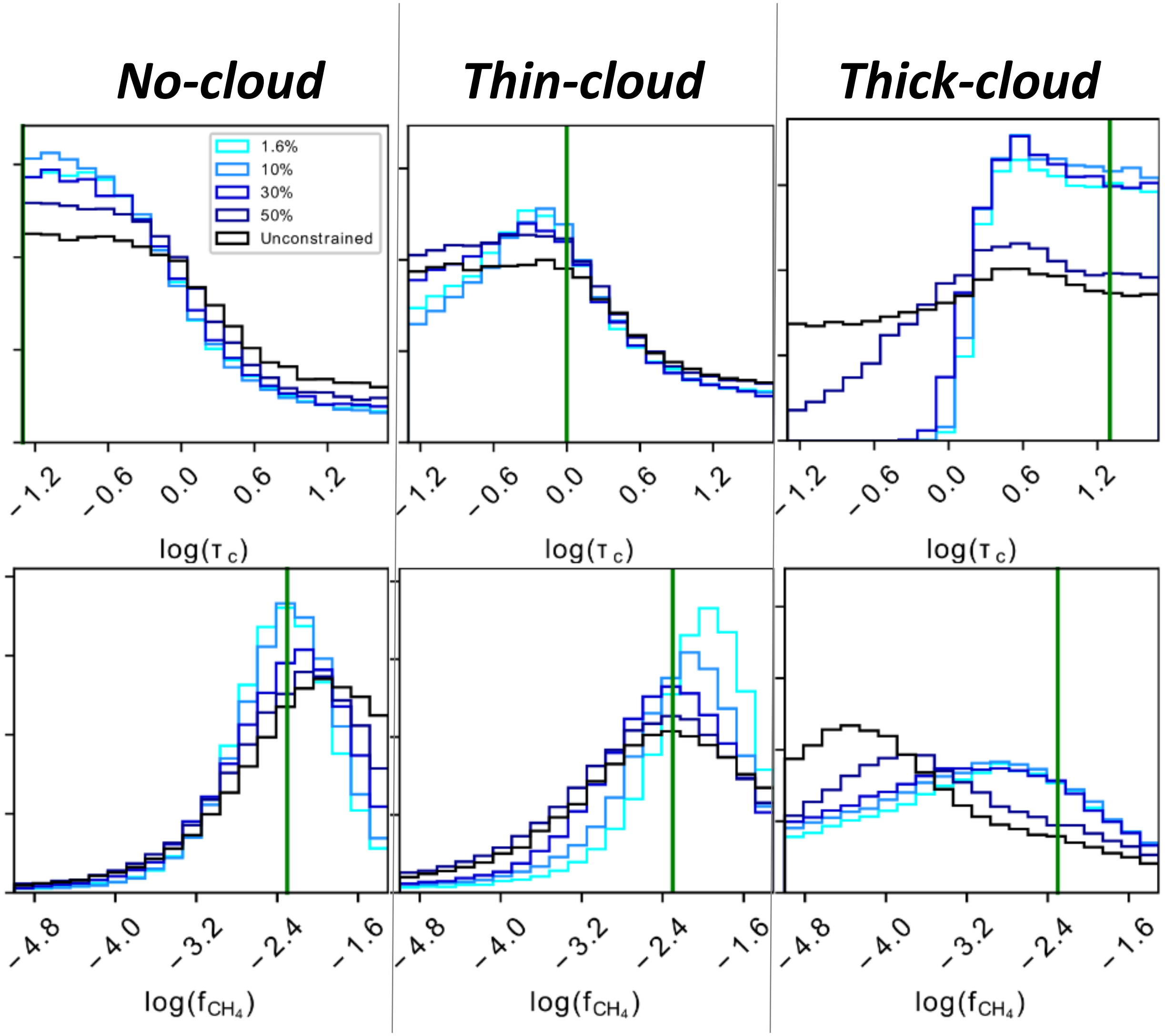
(7D param. space)

Results

If we known a priori the value of R_p, even with some degree of uncertainty in the estimates (see plots), the retrievals improve.

Table: *True* values of the atmospheric configuration for each of the scenarios considered.

Parameter	*No-cloud*	*Thin-cloud*	*Thick-cloud*
τ_c	0.05	1.0	20.0
Δ_c/H_g	2	2	2
$\tau_{c\rightarrow TOA}$	$9.1 \cdot 10^{-3}$	$9.1 \cdot 10^{-3}$	$9.1 \cdot 10^{-3}$
r_{eff} [μm]	0.50	0.50	0.50
ω_0	0.90	0.90	0.90
f_{CH_4}	$5 \cdot 10^{-3}$	$5 \cdot 10^{-3}$	$5 \cdot 10^{-3}$
R_p/R_N	0.6	0.6	0.6



Impact and future work

Carrión-González et al. (2020)
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Findings	New questions
We analysed how planet parameters shape the reflected-light spectra of exoplanets that missions like NGRST (former WFIRST) will measure.	How many of those 4100 exoplanets will be detectable by direct-imaging missions? How good is their orbital characterization?
We showed that knowing the planet radius will improve the atmospheric retrievals.	What are the prospects for constraining the radius of long-period exoplanets? Which synergies with missions like TESS or PLATO can we establish?
Even in the best case, where the value of R_p is known, we observe multiple degeneracies between model parameters that prevent constraining atmospheric properties such as the cloud composition.	Could we develop observing strategies in order to increase the information obtained from these measurements?
If R_p is unknown, we found that direct-imaging observations could constrain it to within a value of $\sim$2.	How this could help discarding some possible bulk compositions of such exoplanets?