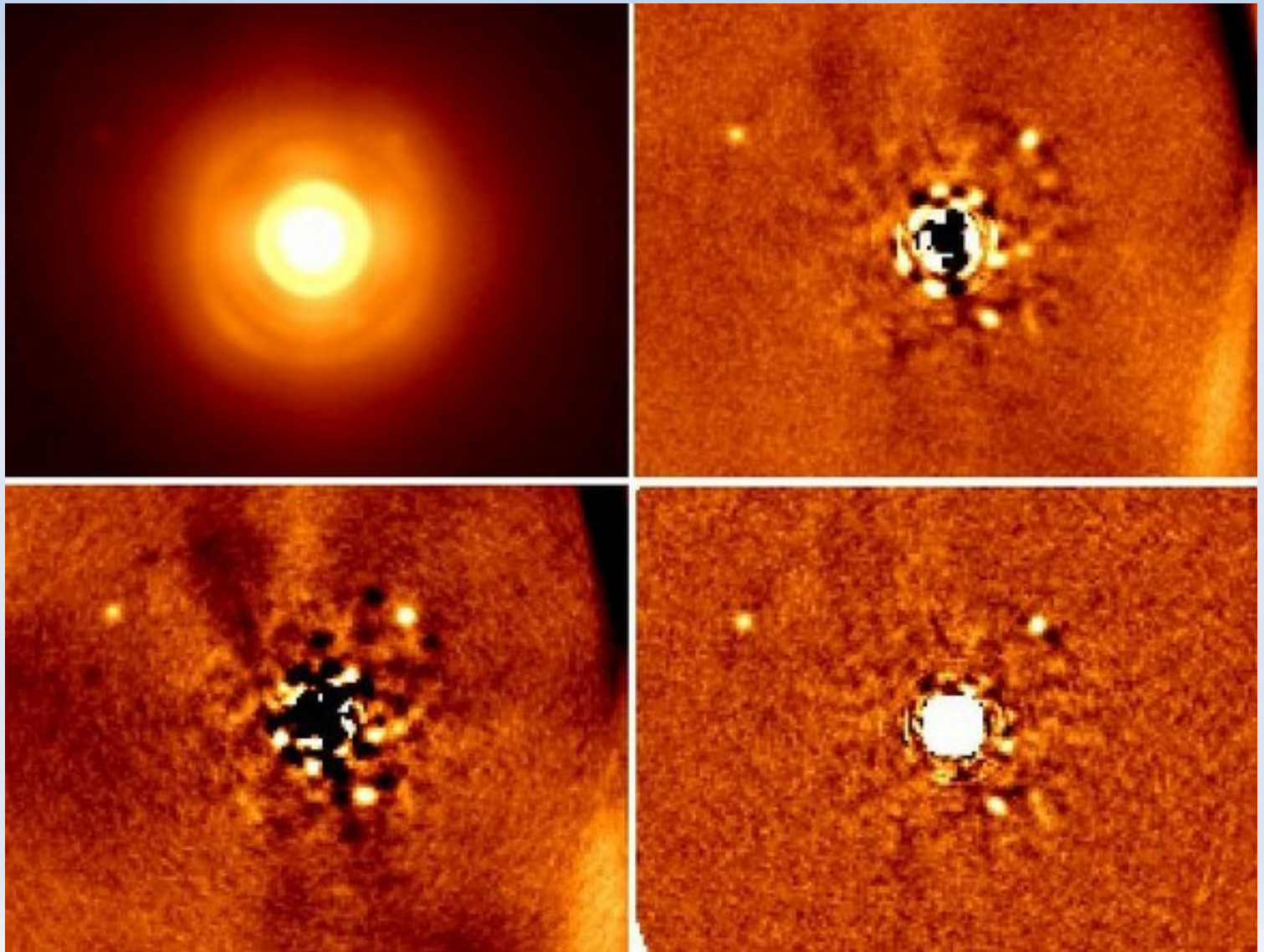
Abundances from direct mid-resolution spectroscopy of exoplanets

Mostly taken from Konopacky et al.2013 and Line et al. 2014



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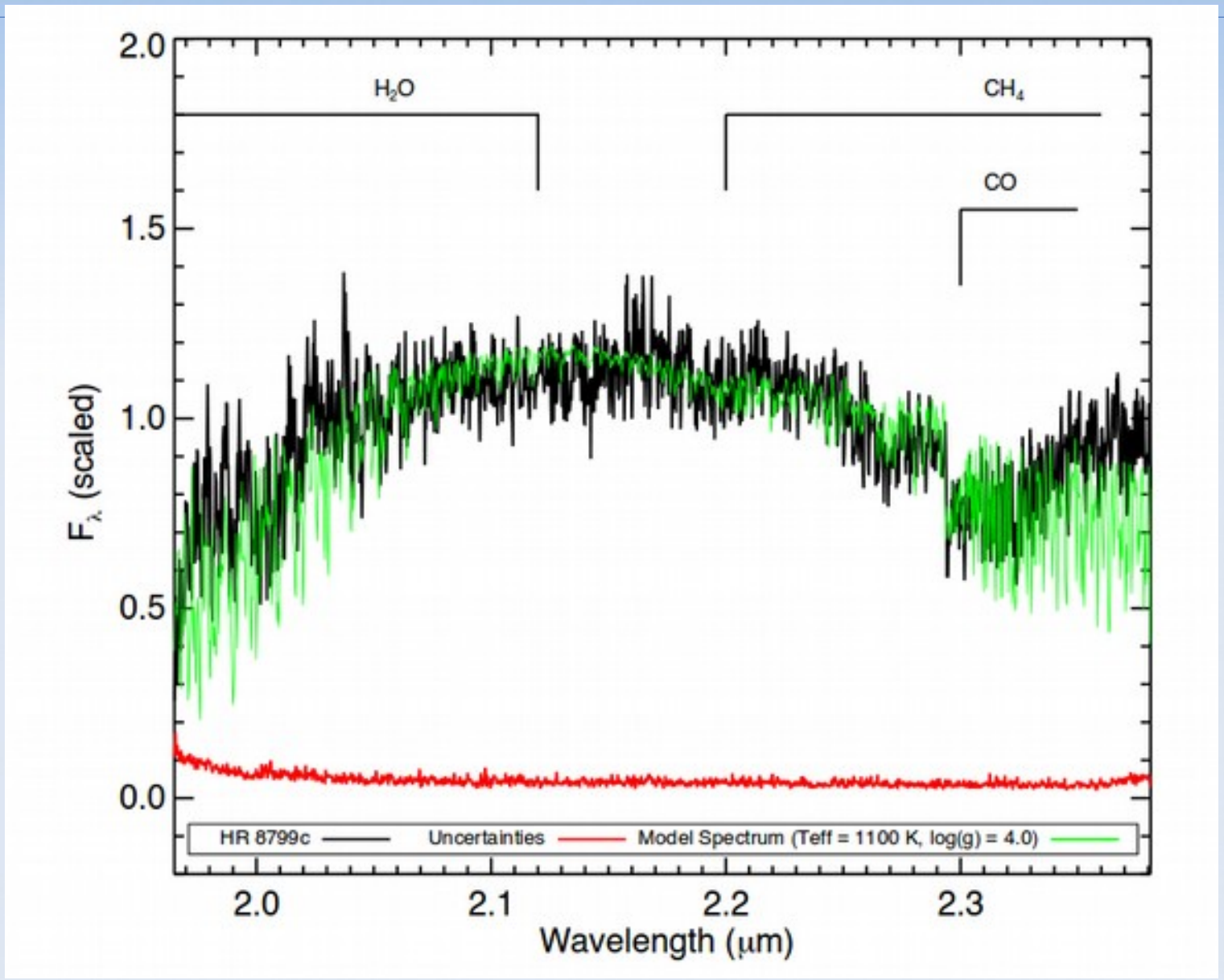
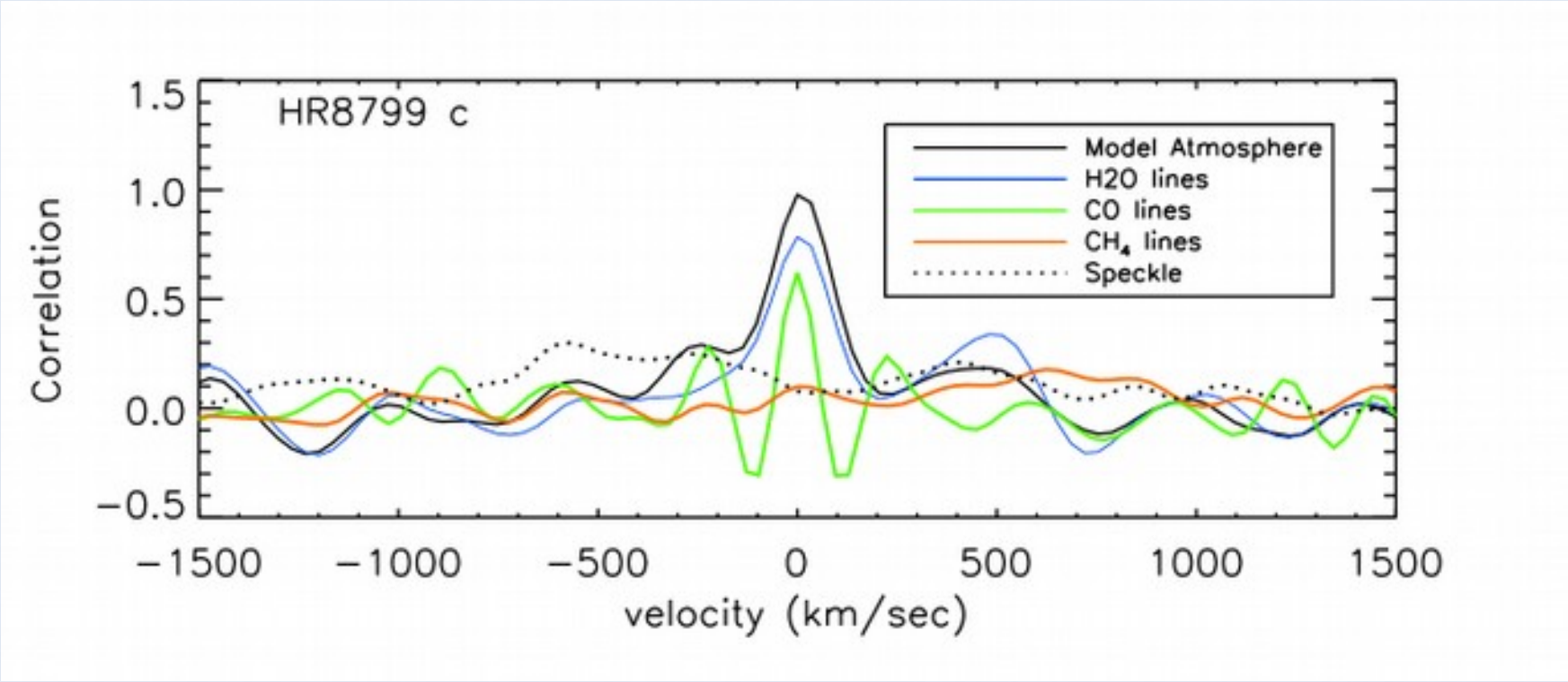
The data



5.5hr NIR spectroscopy from OSIRIS (@Keck) R~4000

Taking on abundances

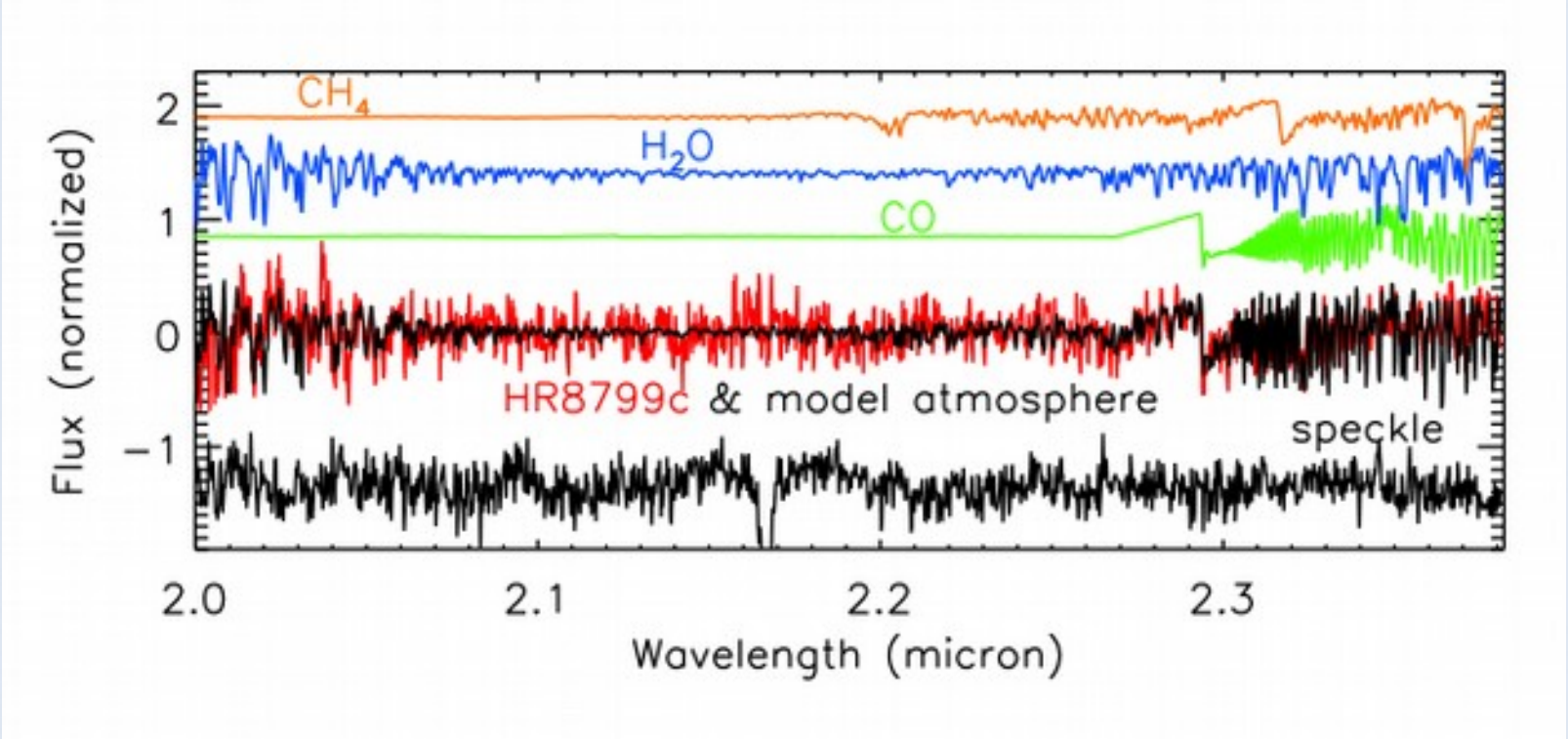
First step :
Cross correlation with theoretical line lists :
H_2O, CO, but no CH_4



Taking on abundances

Second Step :

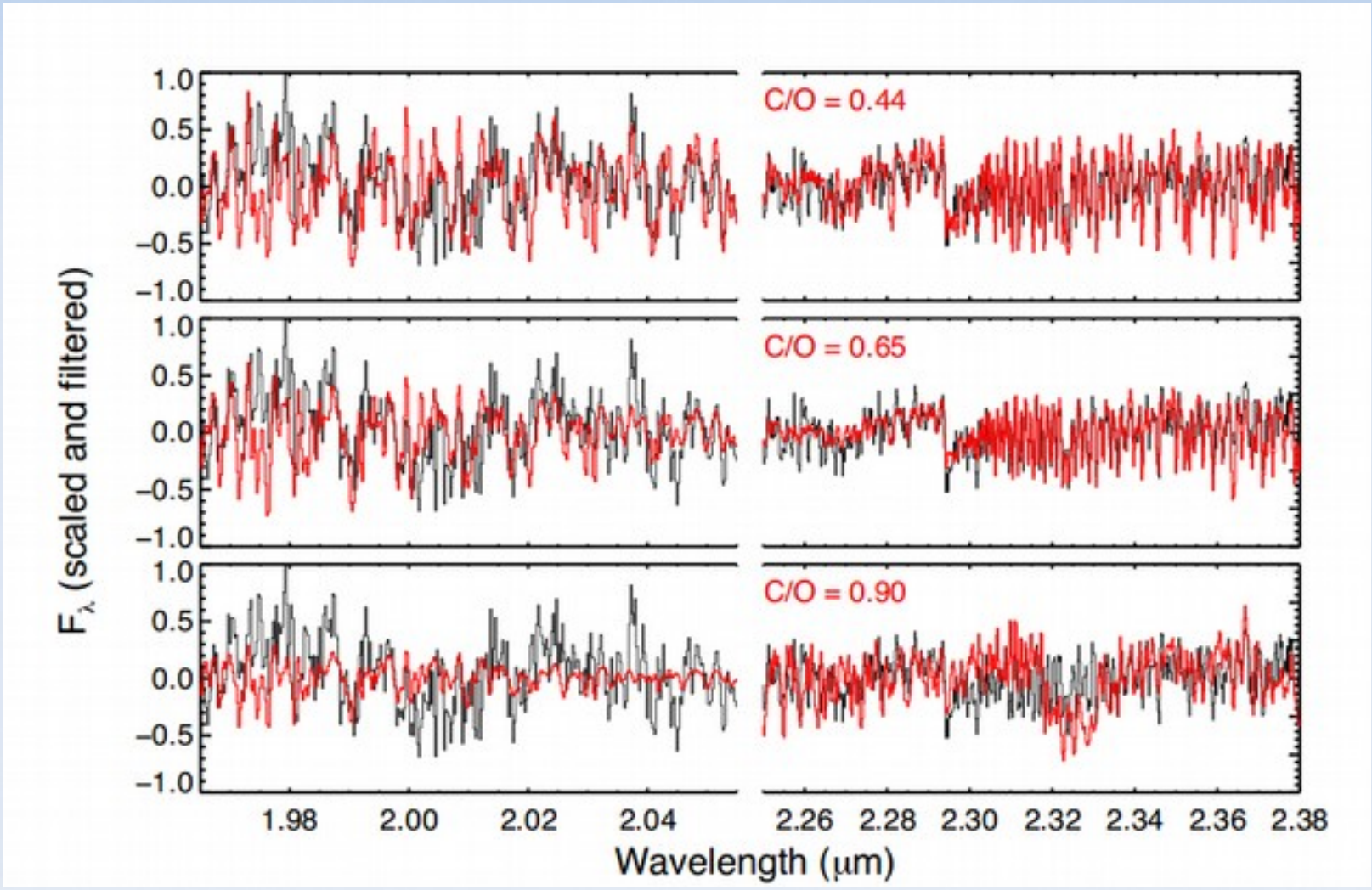
High pass filtering to highlight high resolution features such as lines



Taking on abundances

Third step :

Model fitting to find the « best » C/O



Line et al 2014 approach

« Data driven approach rationale »

X : state vector (i.e. Teff, log g, abundance1, … abundance n...)
Y : Observation vector (i.e. fluxes at given wavelength)
Y=F(X)
Usually F(X) is the model and we compare F(X) to Y to retrieve X

The idea is to invert the problem and directly find X analytically

« Bayesian approach »
They formulate the problem as :
Finding P(X|Y)

Bayes theorem : P(X|Y)# P(Y|X) . P(X)
Where P(X) is called the prior probability of having given state vector

Minimising the cost function

After some algebra it comes that the most likely X is the one which minimises this :

$$\chi^2(\mathbf{x}) = (\mathbf{y} - \mathbf{F}(\mathbf{x}))^T \mathbf{S}_\mathbf{e}^{-1} (\mathbf{y} - \mathbf{F}(\mathbf{x})) + (\mathbf{x} - \mathbf{x}_\mathbf{a})^T \mathbf{S}_\mathbf{a}^{-1} (\mathbf{x} - \mathbf{x}_\mathbf{a})$$

X : state vector (i.e. T(z1)...T(zn), log g, abundance1, … abundance n...)
Xa : prior state vector
Sa : Prior allowed variability or confidence (covariance matrix)
Y : Observation vector (i.e. fluxes at given wavelength)
Se : gaussian observational error (diagonal if uncorrelated)
F(X) : « forward model »

Advantages

- Minimisation issues are well known

- Errors on retrieved X are consistently « given » by the covariance matrix

- In theory this is a very optimised approach which provides nice quantitative results in a consistent way.

Weakness

- Huge dependance on the forward model :

- Directly in the minimisation « F(X) »

- By its jacobian in the error determination

But what is this forward model ???

- It needs to take the form of a matrix operator
- One dimension is the number of wavelength bin
- The other the number of input parameters (=length of the state vector)

Inside the forward model

The model atmosphere is parameterized with **five retrievable gases: H2O, CH4, CO, CO2, and NH3**. H2/He continuum absorption is also included where the H2/Hemole fraction (with He/H2=0.193) is computed by subtracting the latter molecules from unity. **All mixing ratios are assumed to be uniform with altitude**

The Freedman et al. (2008) cross section data base was used with the updates to the ammonia and H2 collision-induced opacities described in Saumon et al. (2012). **Alkali metals, metal oxides or hydrides are not included** in this investigation.

The temperature profile is not parameterized, rather the temperature at each model slab is retrieved. However, some smoothing is implemented through the a-prior covariance matrix to prevent overfitting and unphysical oscillations in the profiles.

Is it really a crude model ?

Is it because any new parameter increases the dimension of the problem ?

Could we forward-model using BT-SETTL ?