The non-LTE model of IR emissions of methane in the Titan's atmosphere (and its applications to Earth)

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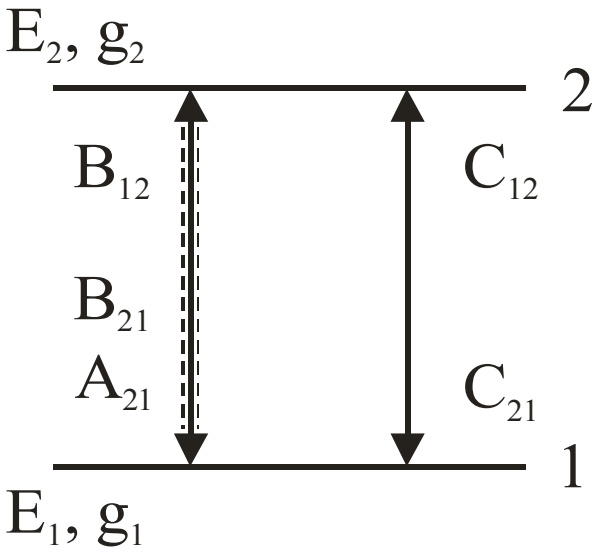
Overview

Above ~400 km in Titan's atmosphere, the assumption of local thermodynamic equilibrium (LTE) breaks down for molecular vibrational levels of methane and various trace gases. Above this altitude non-LTE significantly impacts the formation of mid-infrared ro-vibrational band emissions of these species observed in the limb viewing geometry. We present the detailed model of the non-LTE in methane in the Titan's atmosphere based on the new extended database of spectroscopic parameters for CH_4 as well as on the revised system of collisional V-T and V-V exchange rates. We analyze vibrational temperatures of various CH_4 vibrational levels as well as IR and near IR limb emissions for a number of atmospheric models and compare them with those obtained for the HITRAN-2012 methane spectroscopic parameters. Implications for the CH_4 non-LTE model of the Earth's atmosphere are discussed.

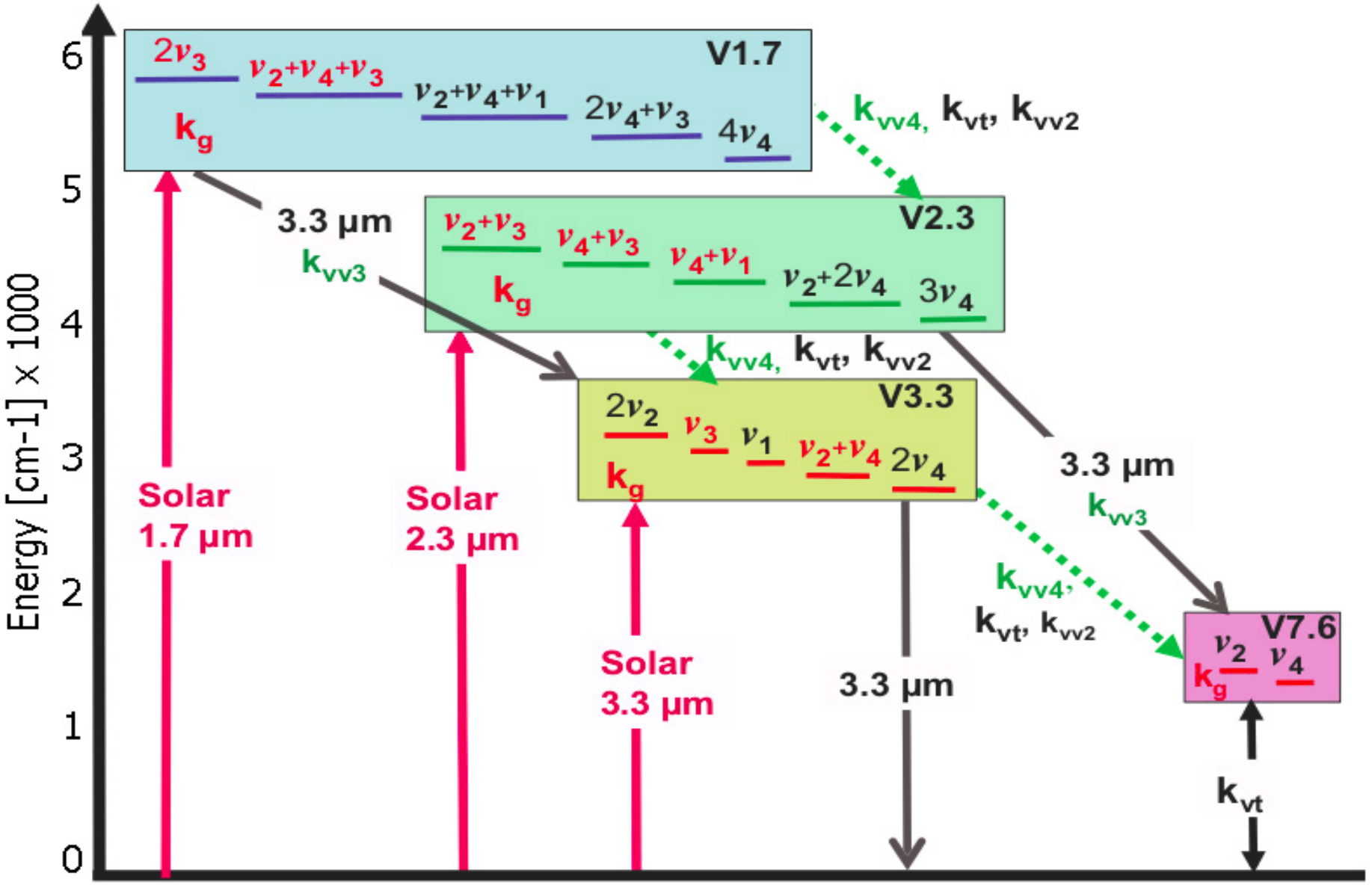
Explaining LTE and non-LTE using 2-level atomic gas



$$\begin{cases} \underbrace{(A_{21} + B_{21}\bar{J})}_{R_{21}} + C_{21}\,)\; n_2 = (\; \underbrace{B_{12}\bar{J}}_{R_{12}} + C_{12})\; n_1 \\ n_1 + n_2 = n \end{cases}$$

- Let's consider an atmosphere of 2-level atomic gas with known P(z), T(z)
- We are interested in calculating the full state of the atmosphere, that means n_1, n_2 at all z.
- At each atmospheric level collisions are local
- Radiation comes from the above and from below
- $C >> R \rightarrow$ local thermodynamic equilibrium (LTE)
- $R \approx C \rightarrow$ non-LTE
- The problem becomes non-local and non-linear.

CH_4 vibrational levels and transitions between them



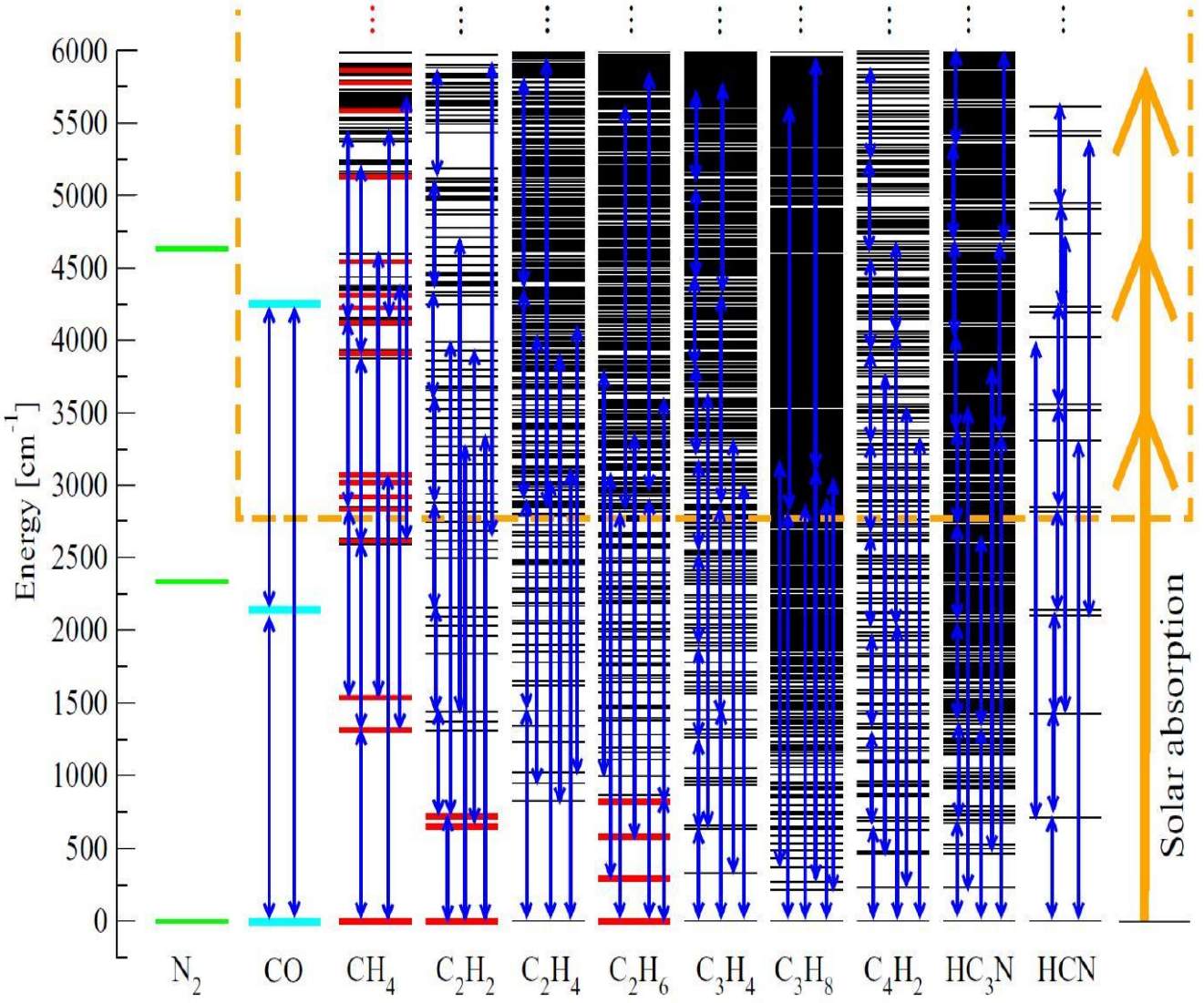
Current Work: detailed non-LTE model of Titan's atmosphere IR emissions

Techniques used

Accelerated lambda iterations (ALI) + opacity distribution functions (ODF):

-- both adopted from stellar astrophysics

-- applied successfully to diagnostics of Earth's and Martian atmosphere limb scans



Levels included in the model of Yelle, 1991

Comparison of the CH_4 data sets

	HITRAN-2012	Garcia-Comas 2011 et al.	Reims-TOMSK (used in this work)
#bands total	63	39	**159**
#bands 7.6m transitions	5	9	**14**
#bands 3.3m transitions	14	12	**34**
#bands 1.7 transitions	5	5	**5**
#bands solar absorption (in the non-LTE model)	34	12	**159**
#bands limb 7.6um (CIRS)	10	16	**54**
#bands limb 3.3 (VIMS)	11	12	**40**

- HIT12 has many poorly presented bands (sometimes only 1-5 lines are presented, especially for higher levels).
- Total # of bands include all transition available among the vib. levels.

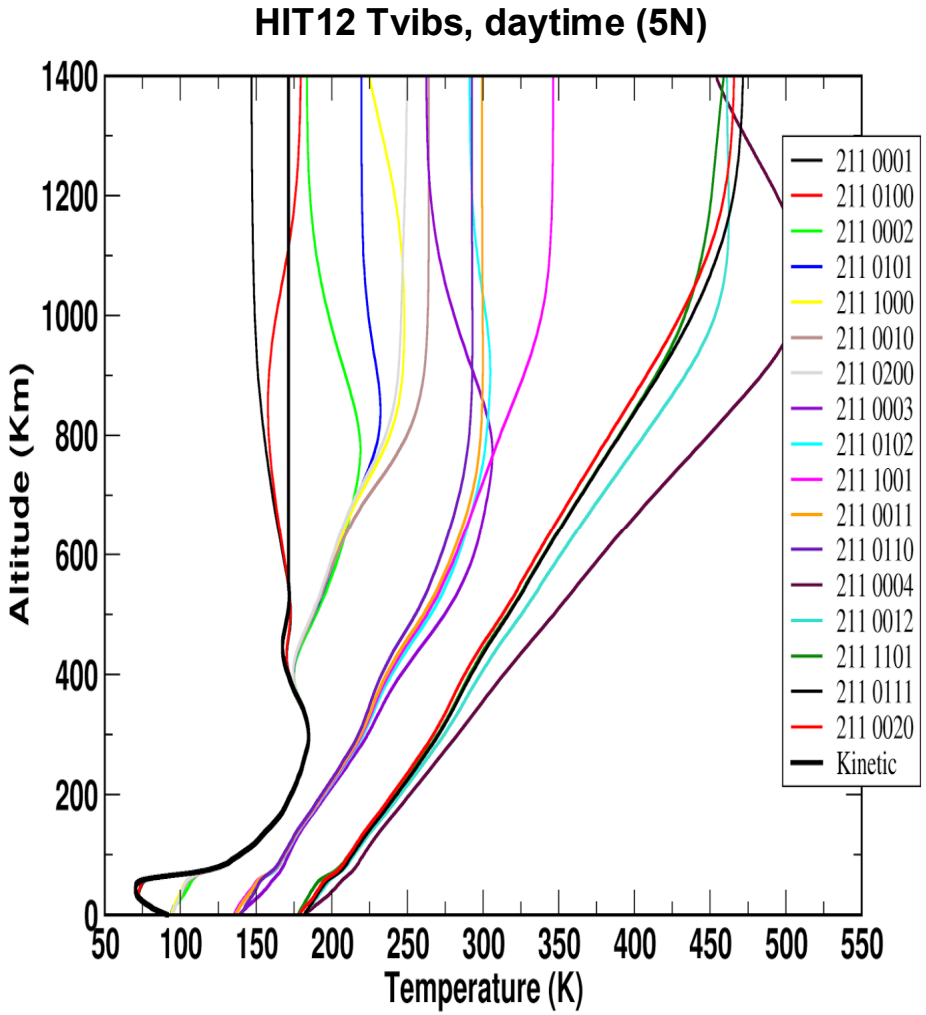
HIT12 #of lines	212 098
TOMSK # of lines	**3 444 517**

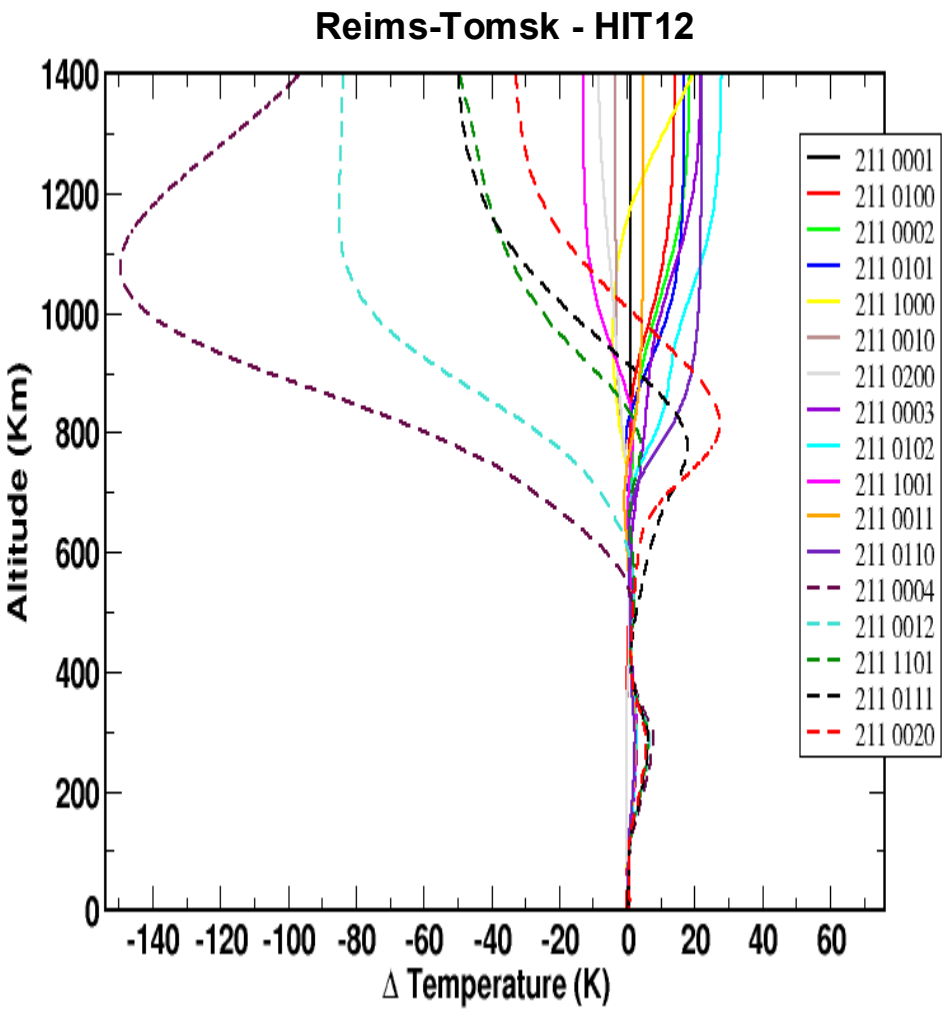
Vibrational temperatures differences for HITRAN-2012 and Reims-Tomsk database, daytime, SZA=45 deg

Vibrational temperature:
LTE: $T_{vib} = T_{kin}$
Non-LTE: T_{vib} deviates from T_{kin}

$$\frac{n_i}{n_0} = \frac{g_i}{g_0} \exp\left[-\frac{E_i}{kT_v}\right]$$

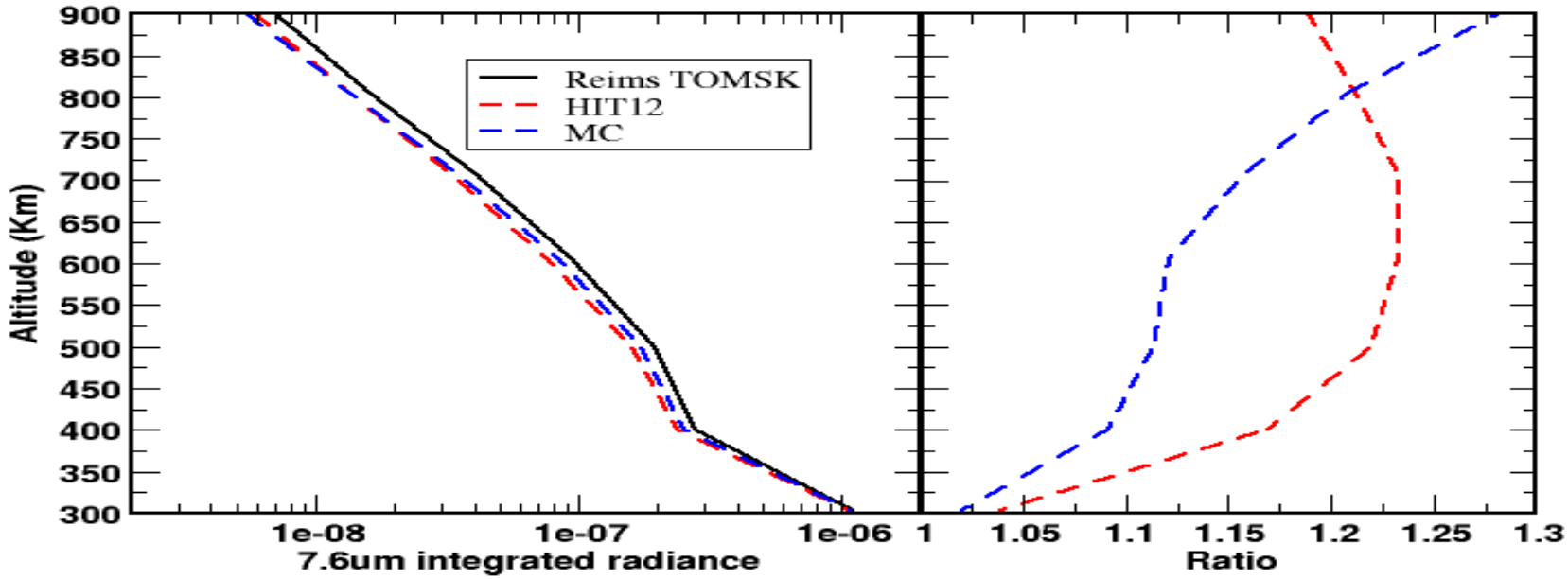
HITRAN/AFGL notation:
211 = 12CH4



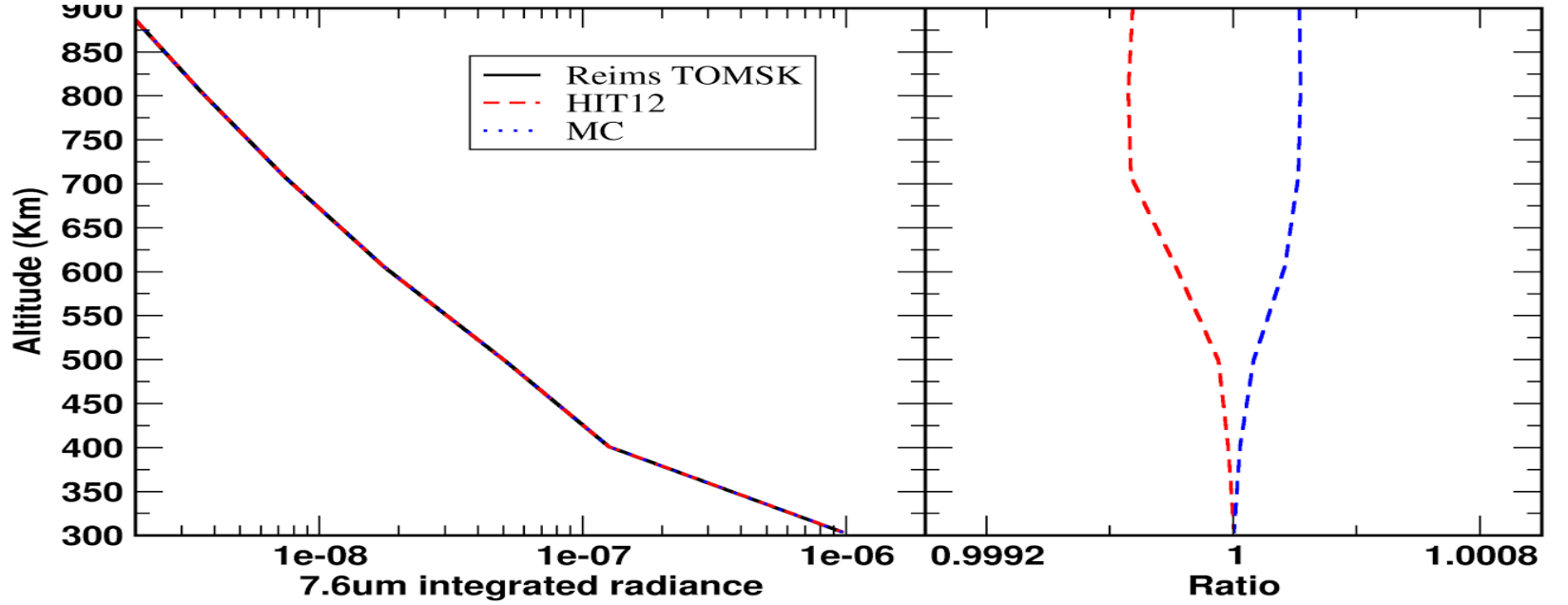


7.6 µm spectrally integrated radiances comparison for different spectroscopic inputs

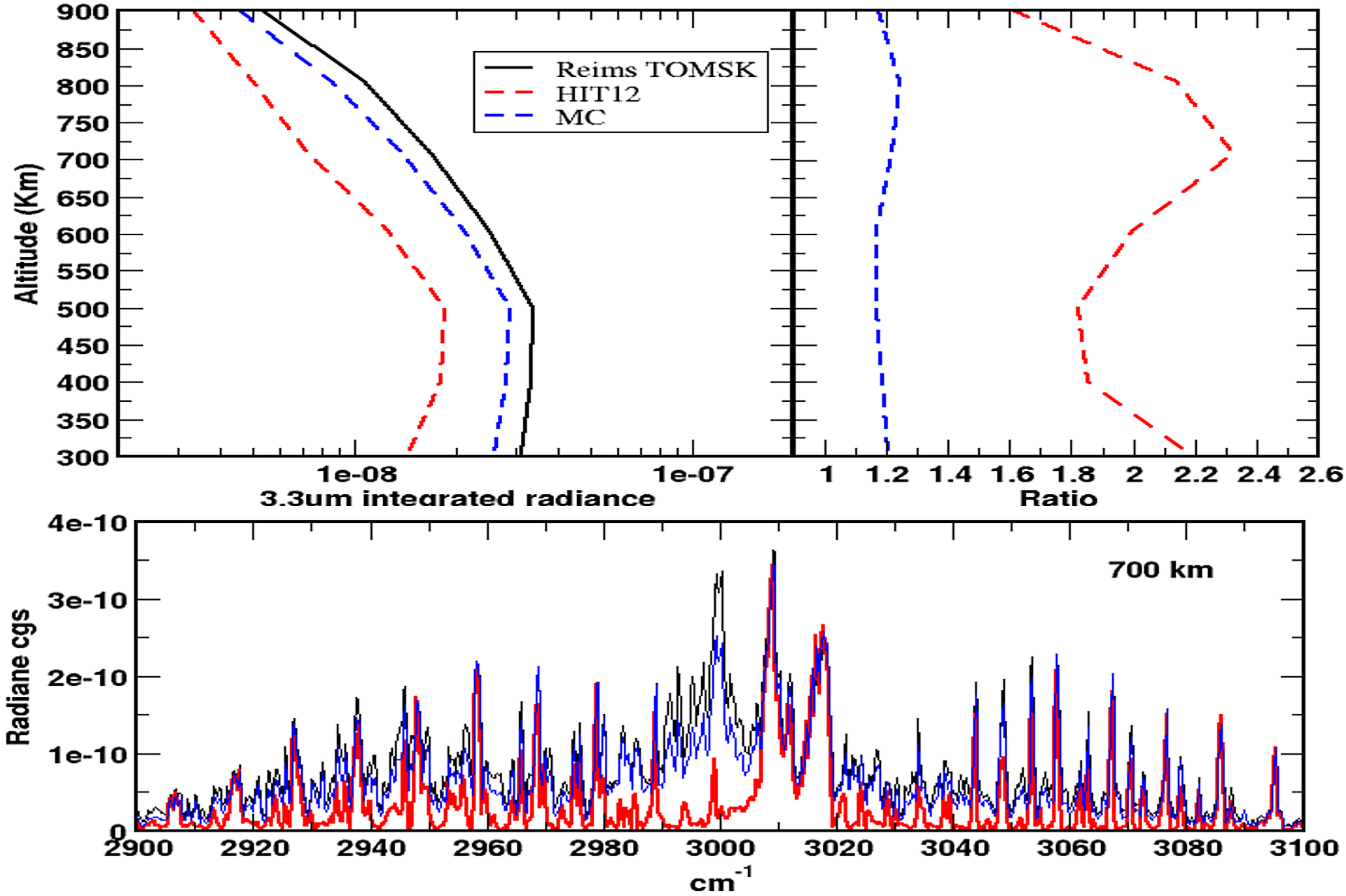
Daytime
SZA=45



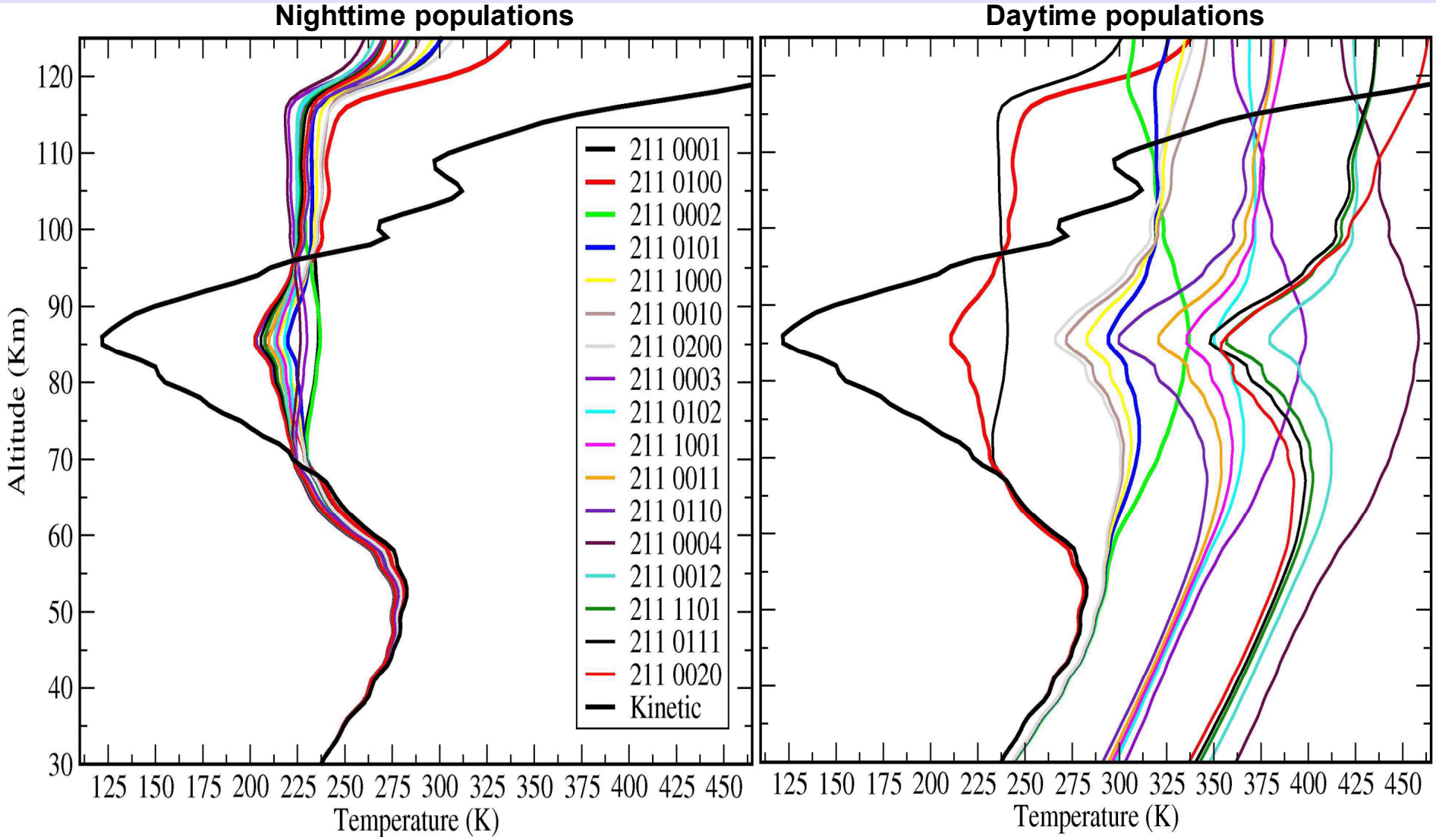
Nighttime



3.3 µm spectrally integrated radiances comparison for different spectroscopic inputs

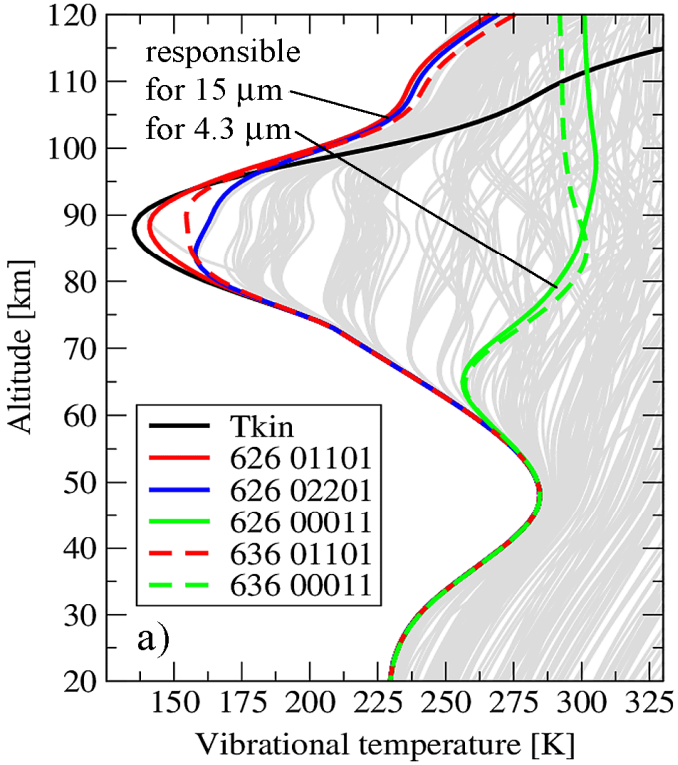


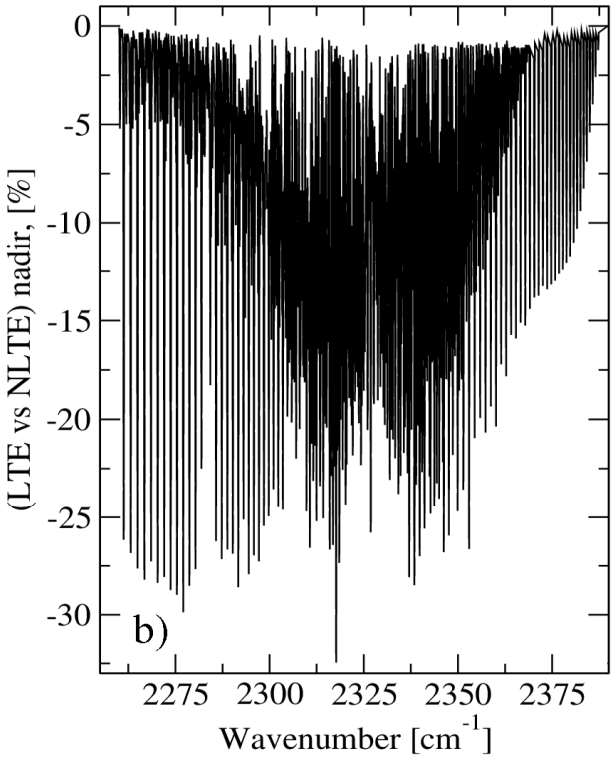
Applications of CH_4 non-LTE model to Earth

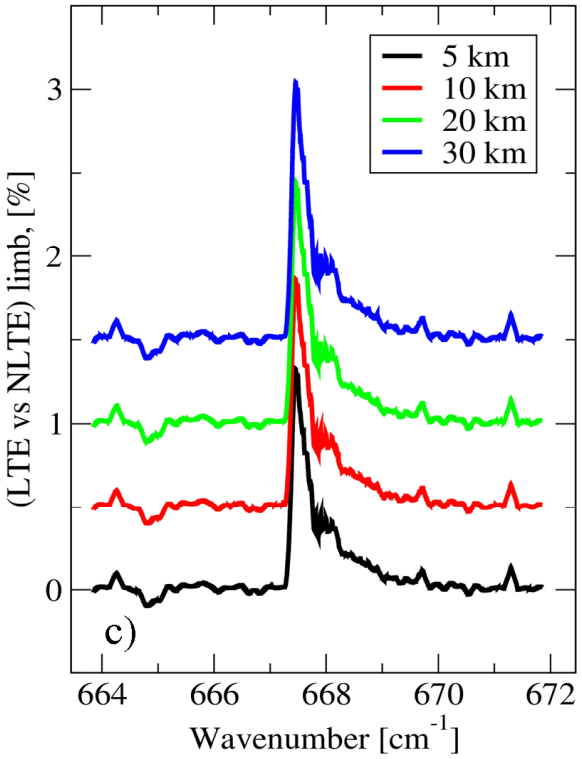


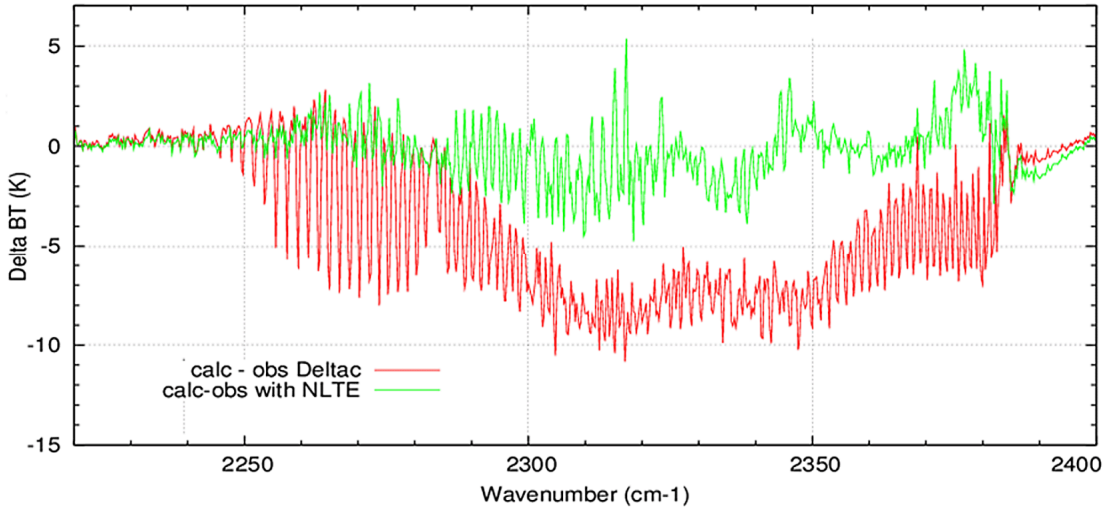
- the non-LTE effects during daytime start above ~65km for the ν_2, ν_4 levels (7.6 μm band)
- ν_1,ν_3 levels (3.3μm band) are out of LTE down to troposphere.

Important: non-LTE contribution to nadir observations









- Tests for CO_2 show an importance of non-LTE contribution for the solar-pumped levels.
- For 4.3 μm band, the difference reaches **30% (!)**
- Needs testing for CH_4 bands, especially for 3.3 μm and shorter λ

Conclusions and further work

- New extended CH4 spectroscopic database of Reims-Tomsk has been applied for the non-LTE modeling of 7.6 μm and 3.3 μm emissions of the Titan's atmosphere
- Up to 10-20% of increase of simulated signal at 7.6 μm in the altitude region 400-800 km (will lead to 2-4 K lower temperatures retrieved from CIRS daytime limb observations)
- Up to 20-25% of increase of simulated signal at 3.3 μm in the altitude region 400-800 km. (will lead to 20-25% decrease of CH4 retrieved from the VIMS daytime limb observations)
- For the atmosphere of Earth, the non-LTE effects during daytime start above ~65km for the ν_2, ν_4 levels responsible for 7.6 μm band while ν_1, ν_3 levels (3.3μm band) are out of LTE down to troposphere.
- Even if the lower layers are in LTE, the non-LTE areas contribute to outgoing radiation detected by satellite sensors.

Future plans

- Application to Titan's CIRS observation (A.Kutepov's NASA grant)
- Testing for the Earth's atmosphere and marking the channels demonstrating high contribution of the non-LTE layers.