NON-LTE DIAGNOSTICS OF BROADBAND INFRARED EMISSIONS FROM MESOSPHERE AND LOWER THERMOSPHERE: APPLICATIONS TO SABER/TIMED

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Outline

- Broadband emission limb radiometry: advantages and disadvantages
- LTE and non-LTE in molecular levels.
- ALI-ARMS non-LTE research code.
- SABER instrument onboard TIMED satellite.
- Peculiarities of temperature, CO_2, and H_2O retrievals from SABER.
- Conclusions.

Broadband infrared emission limb radiometry

"Broadband" here and below refers to the radiance in optical transitions of the molecular bands that covers both the fundamental and hot bands of the considered molecule. The typical spectral window is 100–200 cm^{-1}.

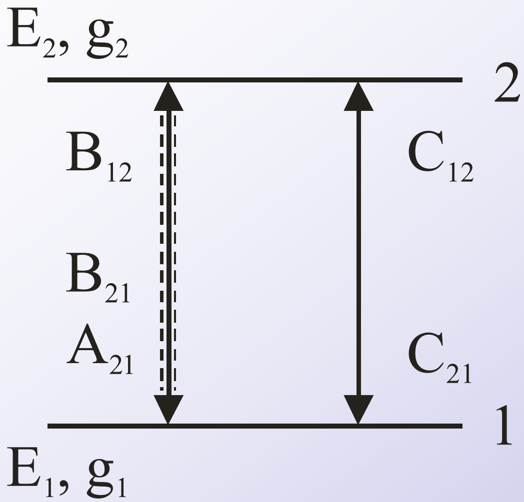
Advantages:

- large signal-to-noise ratio.
- both day- and nighttime measurements.
- good latitudinal and longitudinal coverage.

Difficulties:

- Non-LTE in molecular levels.
- Uncertainties in parameters of rates involved in the model.

LTE and non-LTE: two-level atomic gas example



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

$R << C$

$R_{21}n_2 \sim R_{12}n_1$

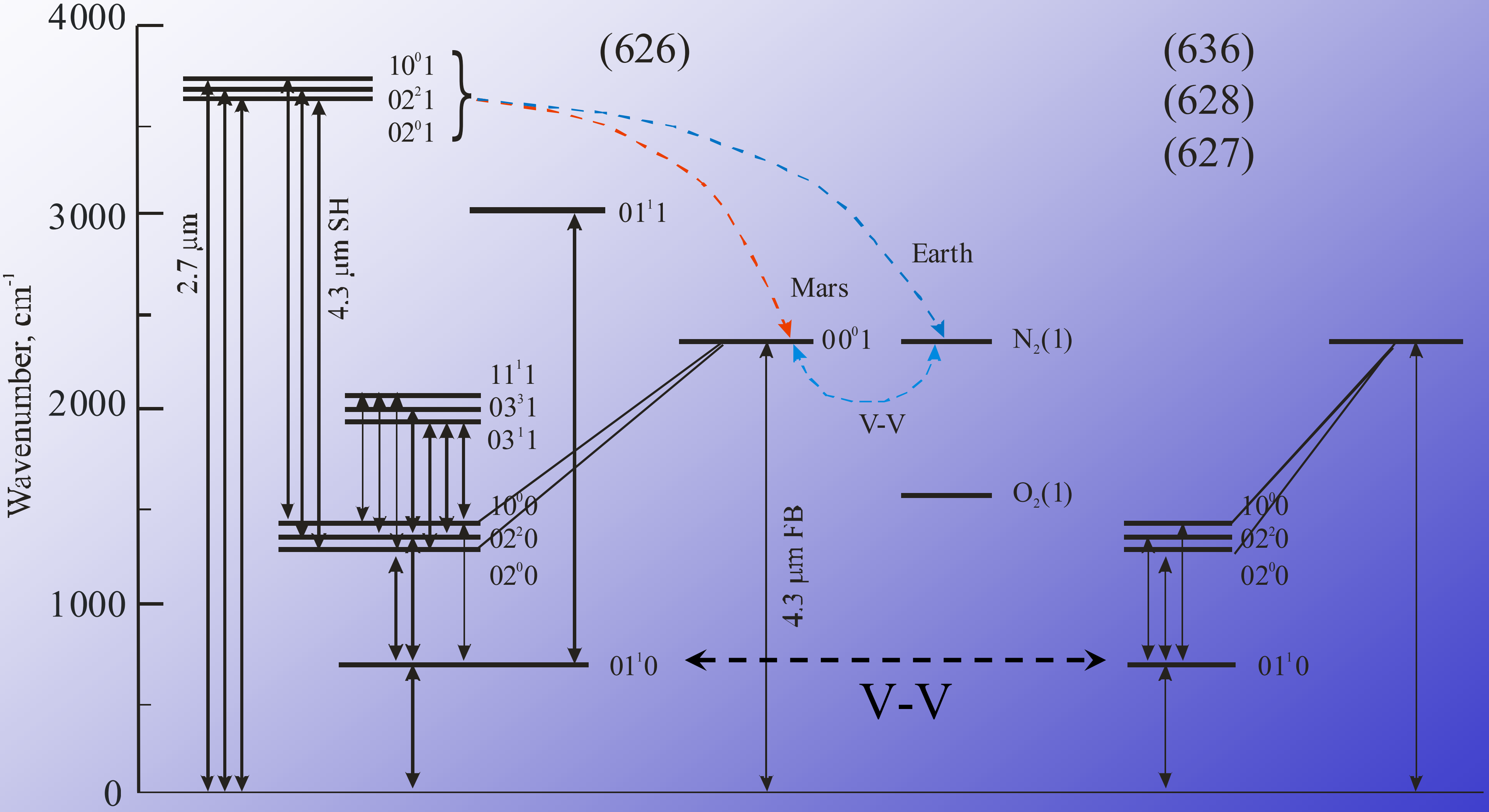
$$n_2 C_{21} = n_1 C_{12}$$

$$\frac{n_2}{n_1} = \frac{g_2}{g_1} e^{-\frac{E_2 - E_1}{kT}}$$

LTE

Otherwise - non-LTE !!!

Energy exchange processes important for CO_2 vibrational levels populations



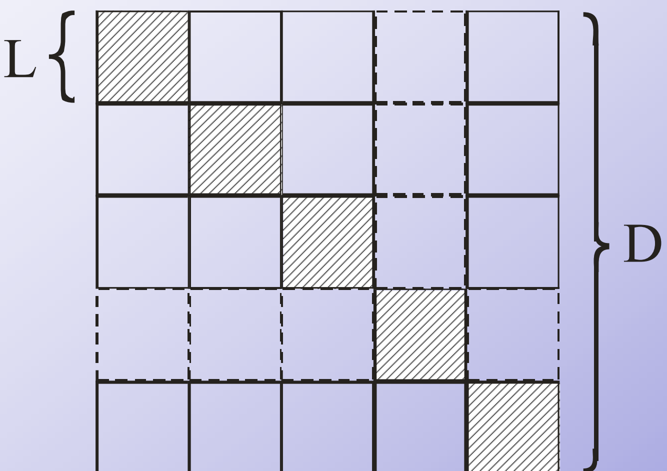
Multi-level non-LTE problem

$$n_l \sum_{l'} (R_{ll'} + C_{ll'}) = \sum_{l'} n_{l'} (R_{l'l} + C_{l'l}) + P_l - L_l$$

$$\sum_l n_l = n$$

Lambda iteration

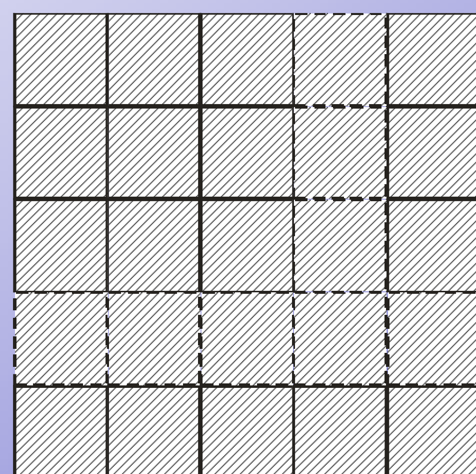
$J = \Lambda\,[\overline{S}]$



$L \times L \times D = DL^2$

Unsöld, 1920s
Wintersteiner et al, 1992

Matrix method



$(L \times D) \times (L \times D) = D^2 L^2$

Curtis & Goody, 1956
Lopez-Puertas et al, 1986

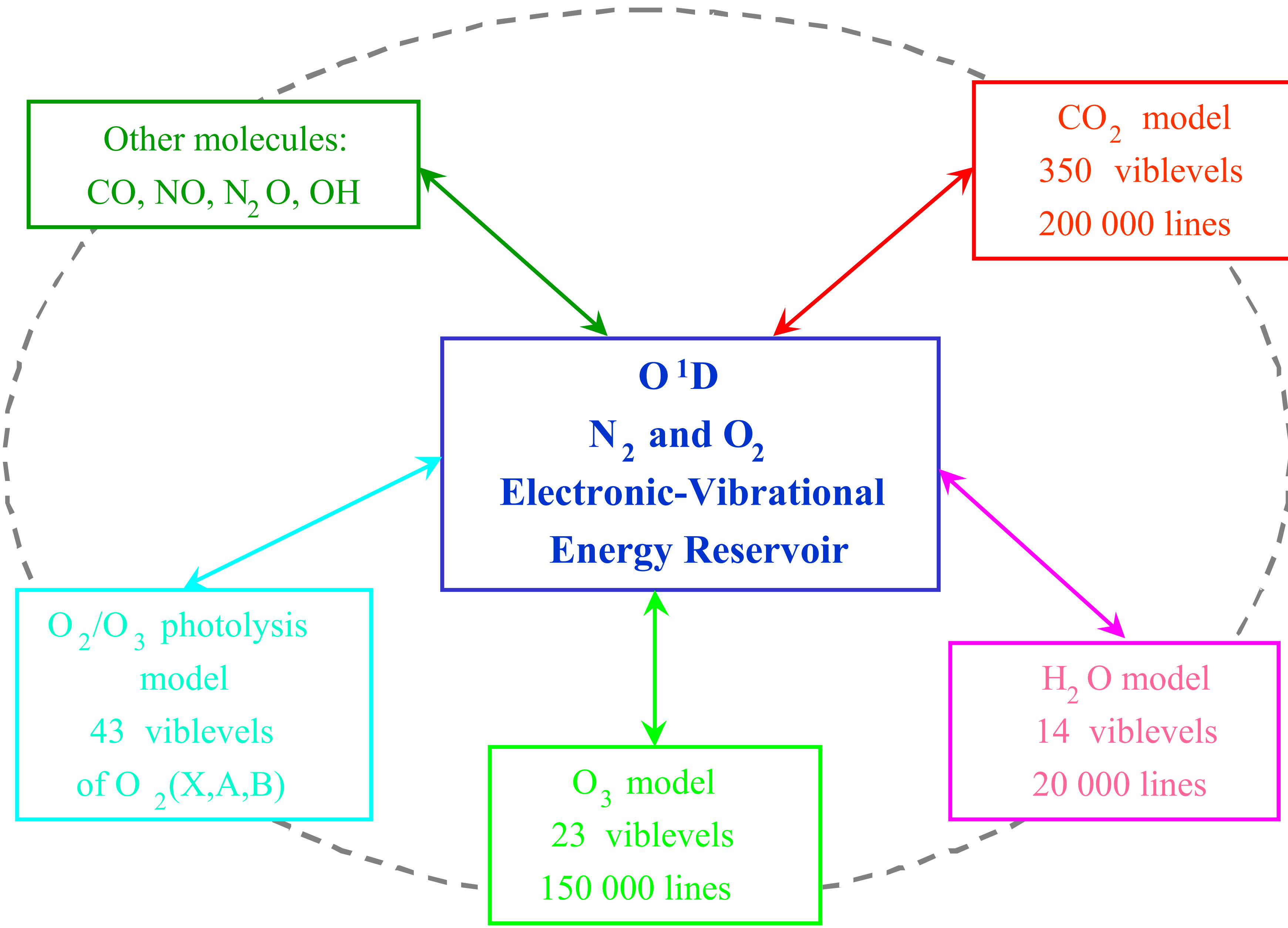
Accelerated Lambda Iteration (ALI)

$$\Lambda = \Lambda^* + (\Lambda - \Lambda^*)$$

ALI technique avoids expensive radiative transfer calculations for the photons trapped in the optically thick cores of spectral lines.

Rybicki & Hummer, 1991
Kutepov et al., 1998

Current status of ALI-ARMS non-LTE model



Applications of ALI-ARMS non-LTE code

- Radiative cooling/heating rate calculations in the molecular bands in the atmospheres of:
  - Earth [Kutepov et al., 2007]
  - Mars [Hartogh et al., 2005].

- Analysis of satellite measurements:
  - CRISTA-1,2 [Kaufmann, 2002, 2003; Gusev 2006],
  - **SABER** [Kutepov et al., 2006; Feofilov et al, 2009].

The SABER instrument aboard the TIMED satellite

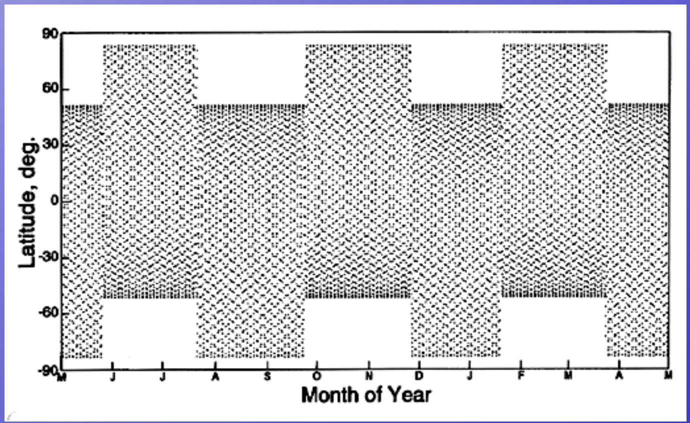
TIMED: Thermosphere, Ionosphere, Mesosphere Energetics & Dynamics
SABER: Sounding of the Atmosphere Using Broadband Emission Radiometry

Mission launched on December 7, 2001
Data available since January 25, 2002
4 instruments: GUVI, SEE, TIDI, **SABER**

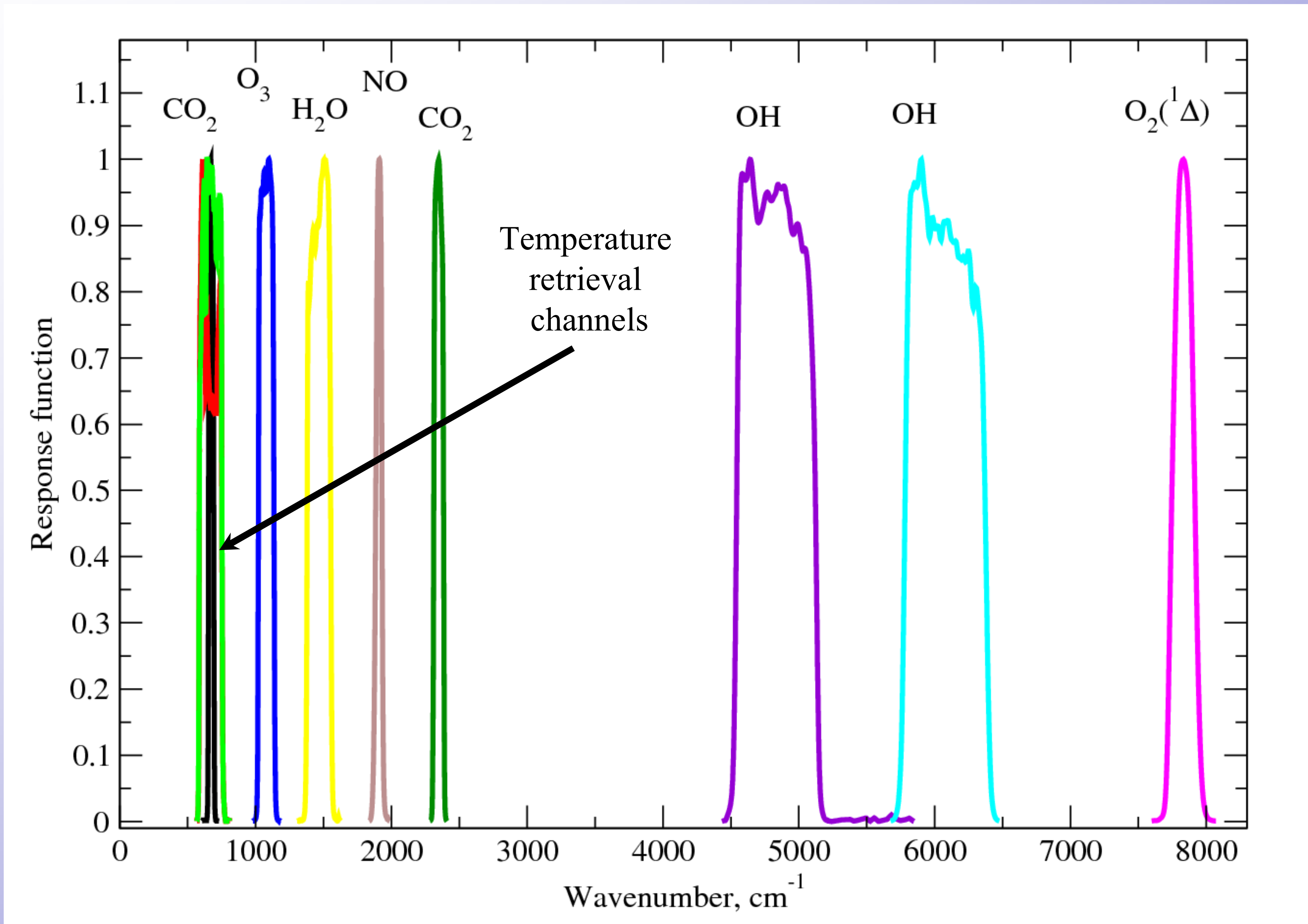
<u>SABER instrument:</u>

- Designed to study the Mesosphere and Lower Thermosphere (MLT).
- Limb scanning infrared radiometer.
- 10 broadband channels (1.27–17 µm)
- Products: kinetic temperature, CO_2, O_3, H_2O, NO, O_2, OH, O, H.

Latitudinal coverage



Bandpass functions of SABER

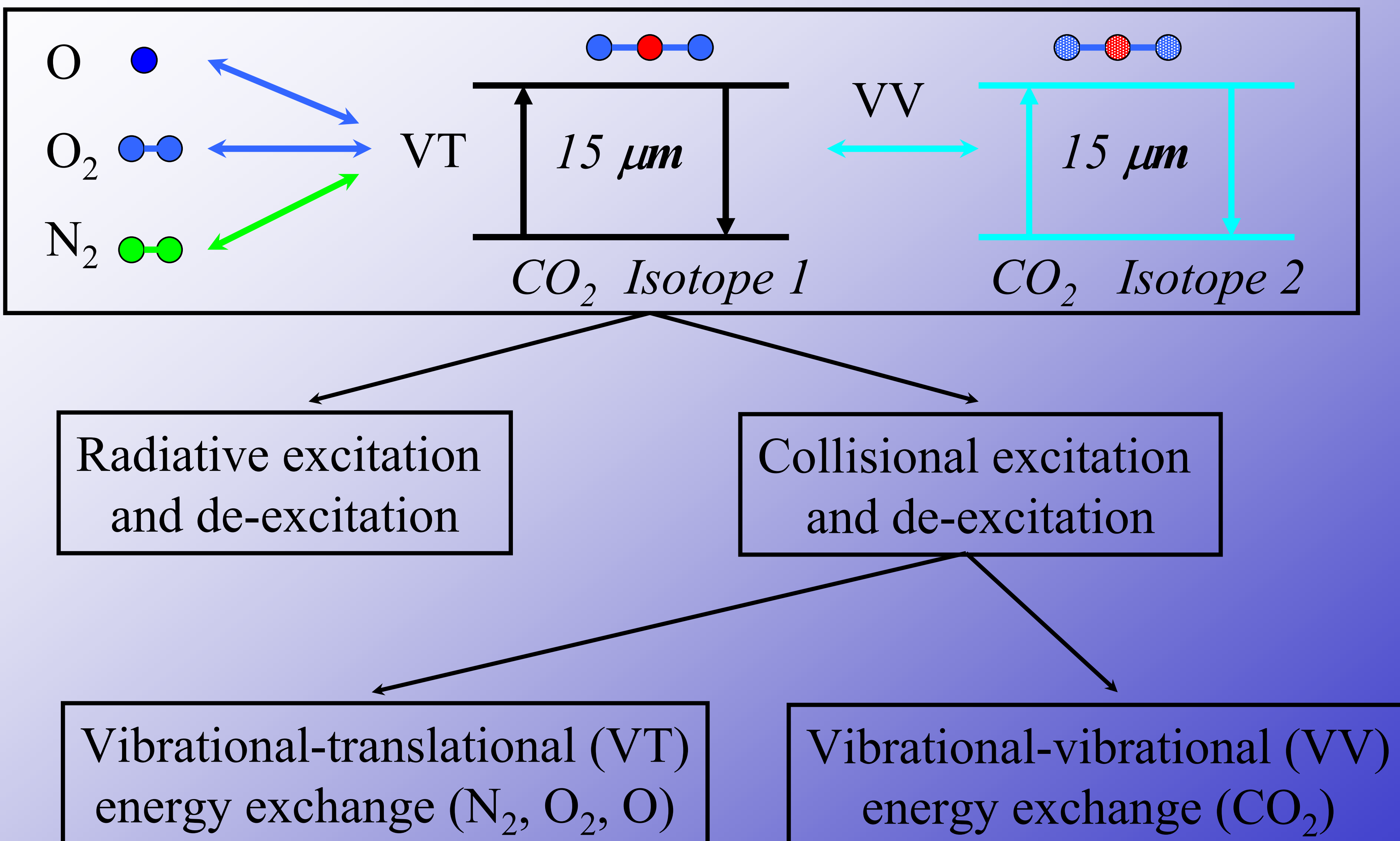


Peculiarities of non-LTE modeling

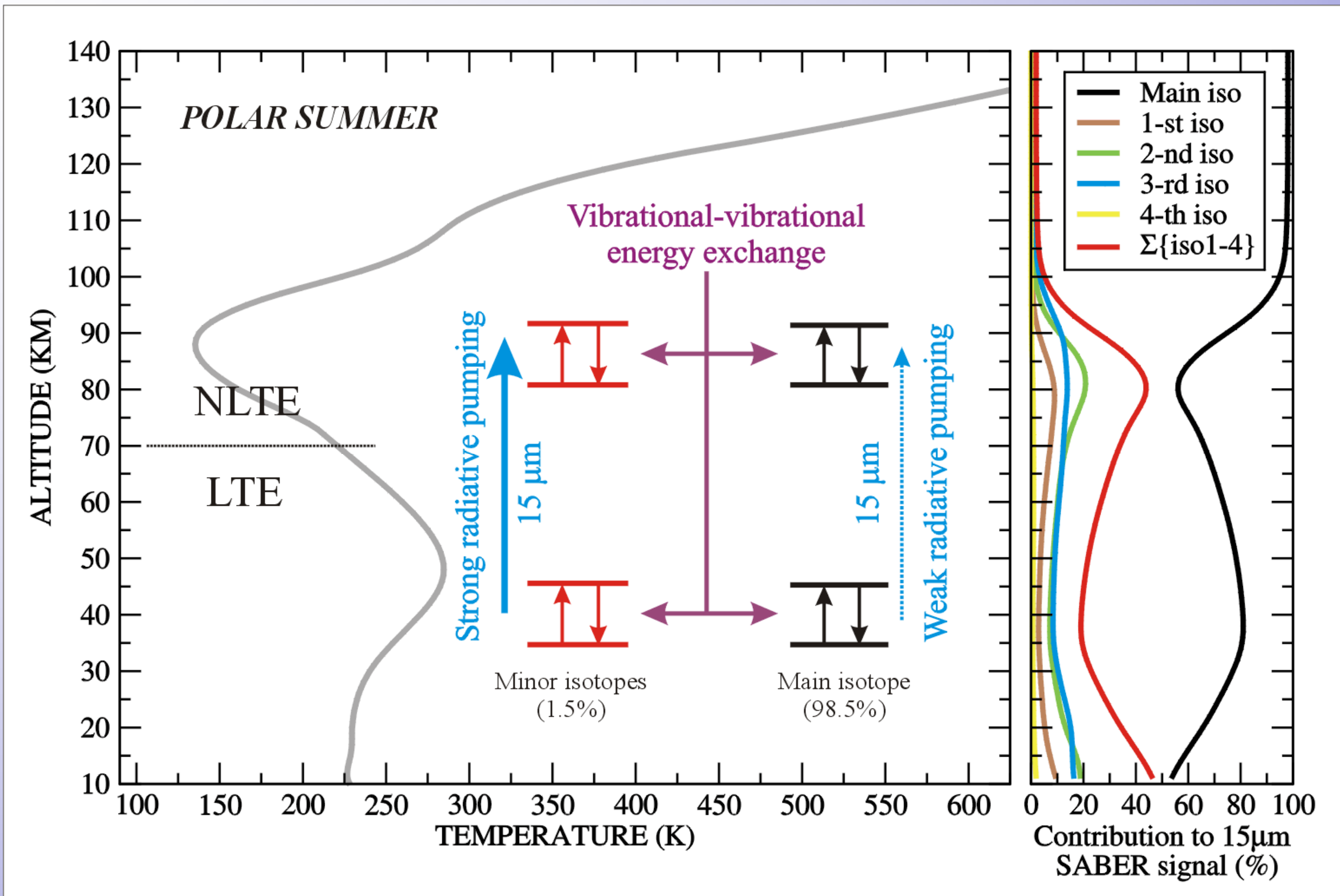
Example 1:

energy exchange among CO_2 isotopes

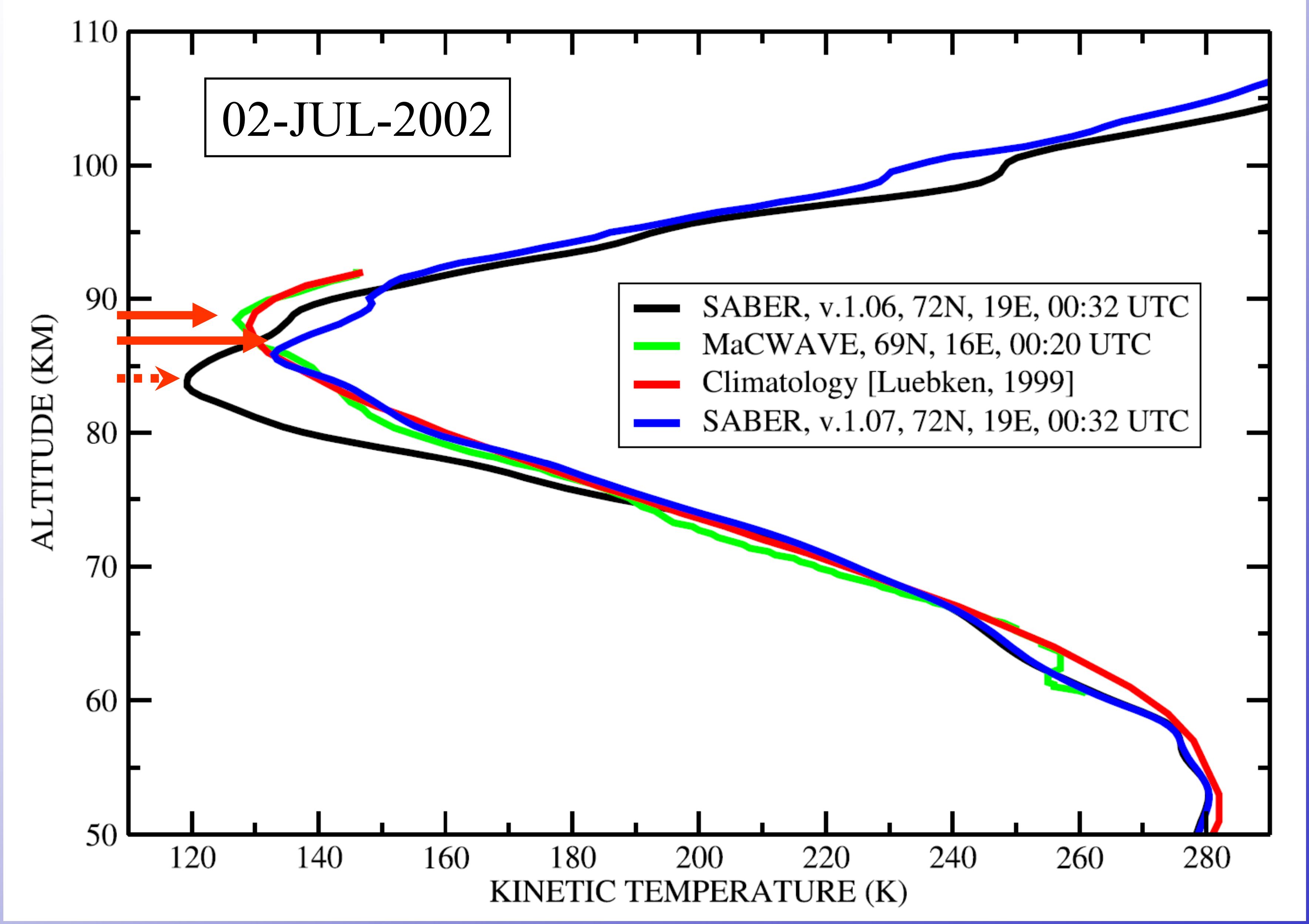
Energy exchange processes for 15μm levels



Temperature retrieval from 15 μm CO_2 radiance



Retrieval with modified SABER non-LTE model

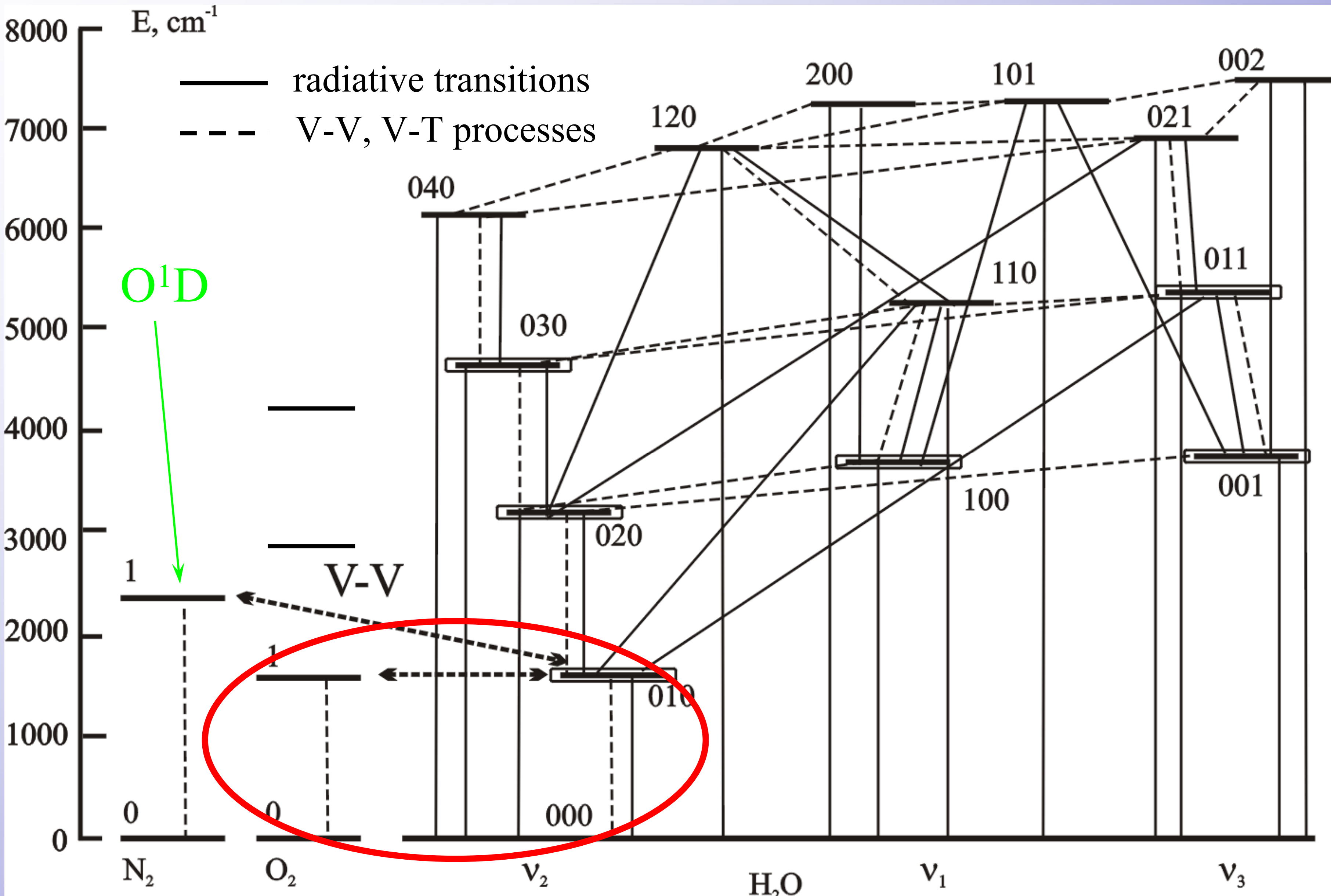


Peculiarities of non-LTE modeling

Example 2:

adjusting rate coefficients for H_2O retrievals

Non-LTE model of H_2O

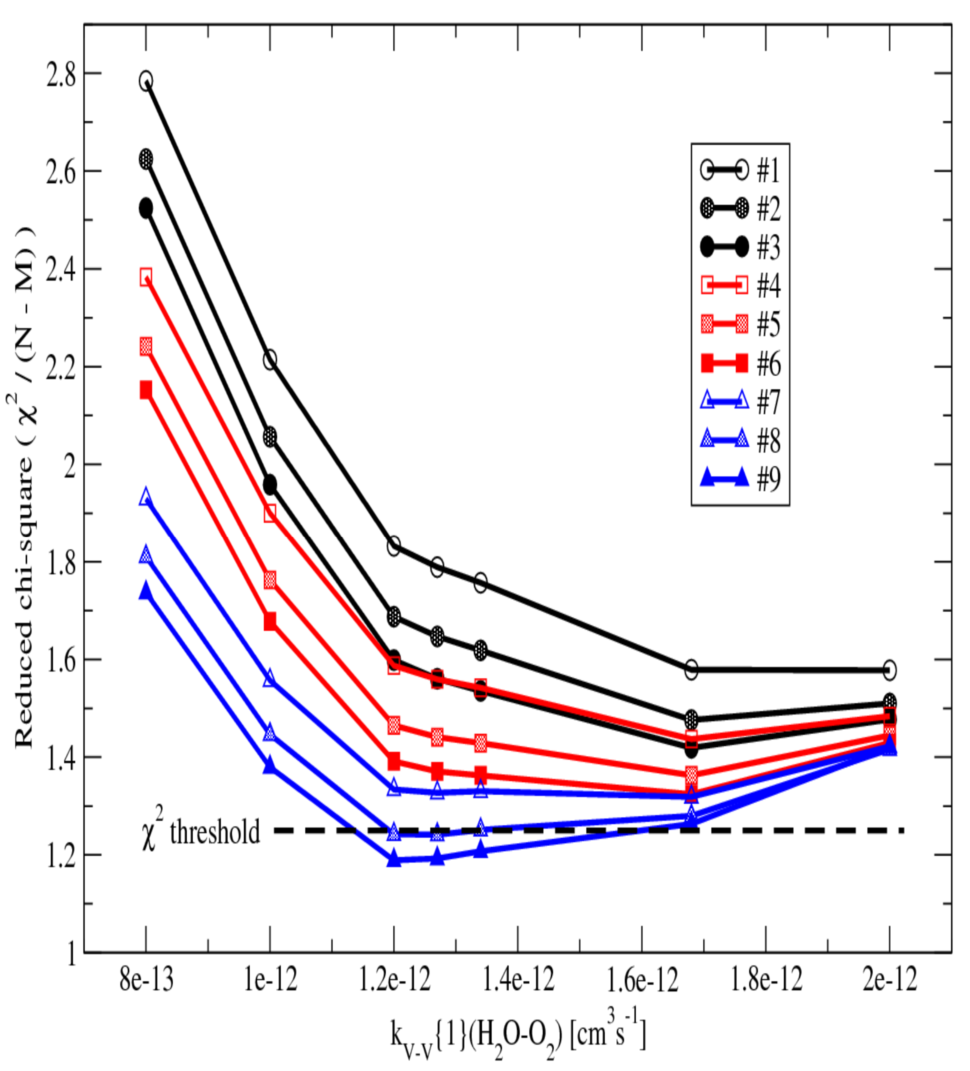


Uncertainties of V-V and V-T rate coefficients

Various measurements of $k_{V-V}\{1\}(H_2O-O_2)$ and $k_{V-T}\{2\}(O_2-O)$ rate coefficients.

Process	Rate coefficient ($cm^3\ s^{-1}$)	References
$k_{V-V}\{1\}(H_2O-O_2)$	5.5×10^{-13}	Huestis, 2006, based on Diskin et al., 1996
	1.0×10^{-12}	Koukuli et al., 2006
	$1.0–3.0\times10^{-12}$	Zaragoza et al., 1998
	1.2×10^{-12}	Zhou et al., 1999
	1.7×10^{-12}	Bass and Shields, 1974
	$1.7–3.1\times10^{-12}$	Edwards et al., 2000
	8.9×10^{-12}	Bass et al., 1976
$k_{V-T}\{2\}(O_2-O)$	1.3×10^{-12}	Breen et al., 1973
	2.0×10^{-12}	Ivanov et al., 2007
	2.6×10^{-12}	Copeland, 2008 Saran et al., 2008
	3.2×10^{-12}	Kalogerakis et al., 2005
	3.4×10^{-12}	Esposito and Capitelli, 2007

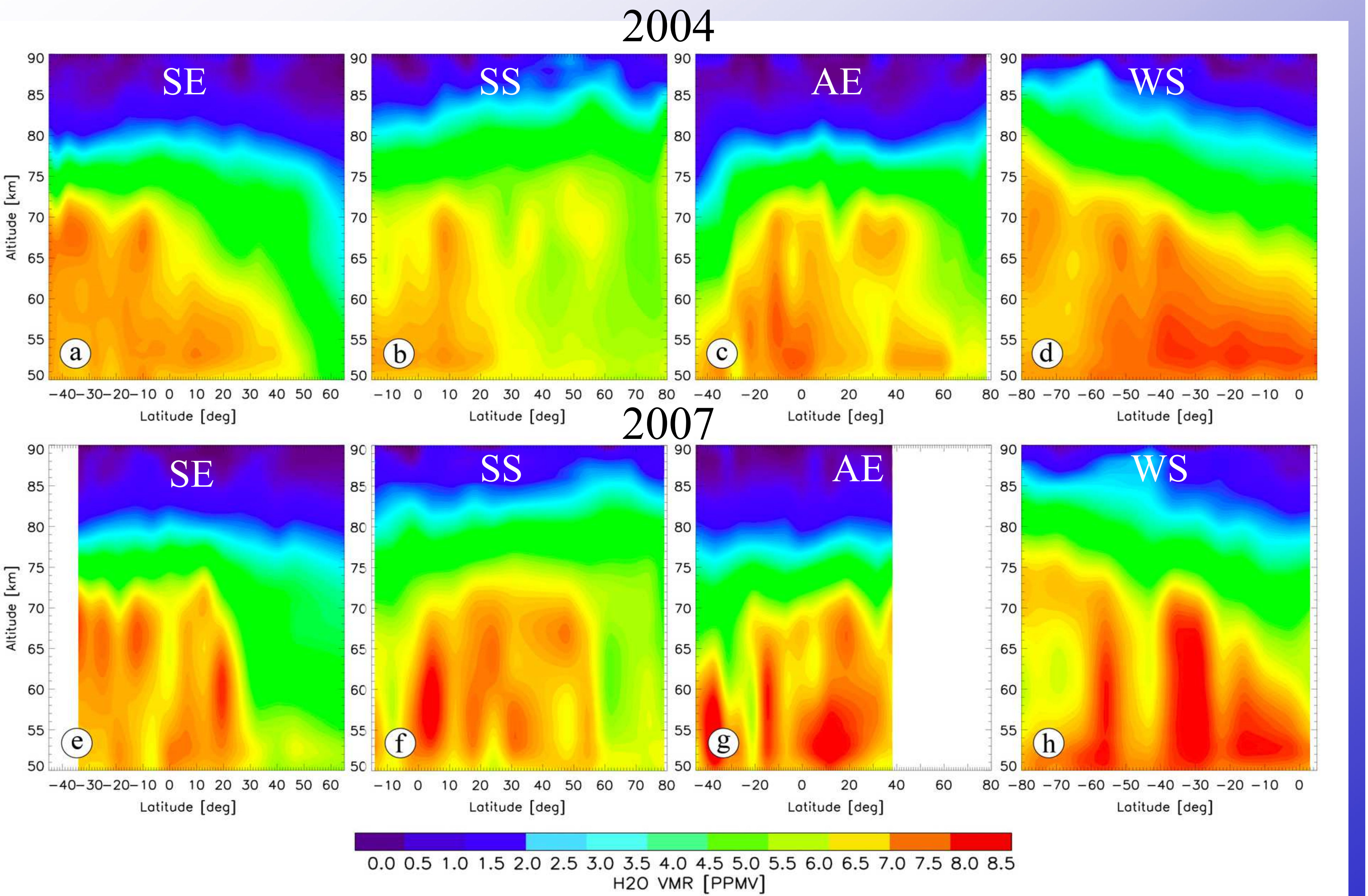
Updating the H_2O non-LTE model



- Selecting the correlative dataset that is not sensitive to non-LTE effects: ACE-FTS.
- Identifying the set of rates that are important for 6.6μm radiance calculation.
- Performing the 7x3x3x40=2520 test runs for 40 overlapping measurements and calculating χ^2.

Minimum χ^2 corresponds to:
$k_{V\text{-}V}\{H_2O\text{-}O_2\}=1.2 \times 10^{-12}$ cm^3s^{-1}
$k_{V\text{-}T}\{O_2\text{-}O\}=3.3 \times 10^{-12}$ cm^3s^{-1}
$k_{V\text{-}T}\{H_2O\text{-}M\}=1.4$ x current rates

Retrievals with updated non-LTE model



Conclusions

- Broadband infrared molecular emission radiometry is a powerful technique that provides information about atmospheric temperature and composition up to lower thermosphere both for day and night conditions.

- The analysis of this information requires complicated non-LTE models that describe all the processes governing the vibrational levels populations.

- In some cases the reaction rates involved in non-LTE models need verification that can be done using nearly simultaneous measurements (or climatology) made by the instruments that are free of non-LTE effects (lidars, microwave, occultation technique).

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