OCO-2 Solar Model Updates

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March 21, 2016

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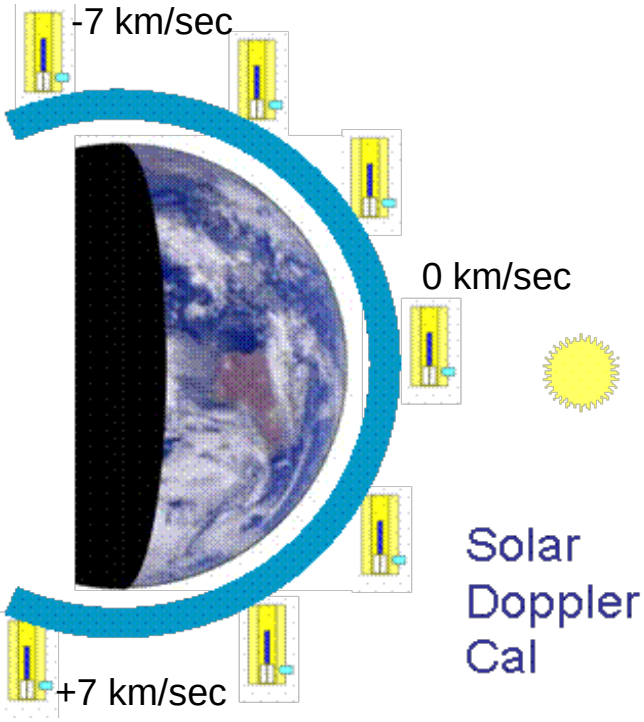
Government sponsorship acknowledged.

On-orbit Solar Calibration Operations

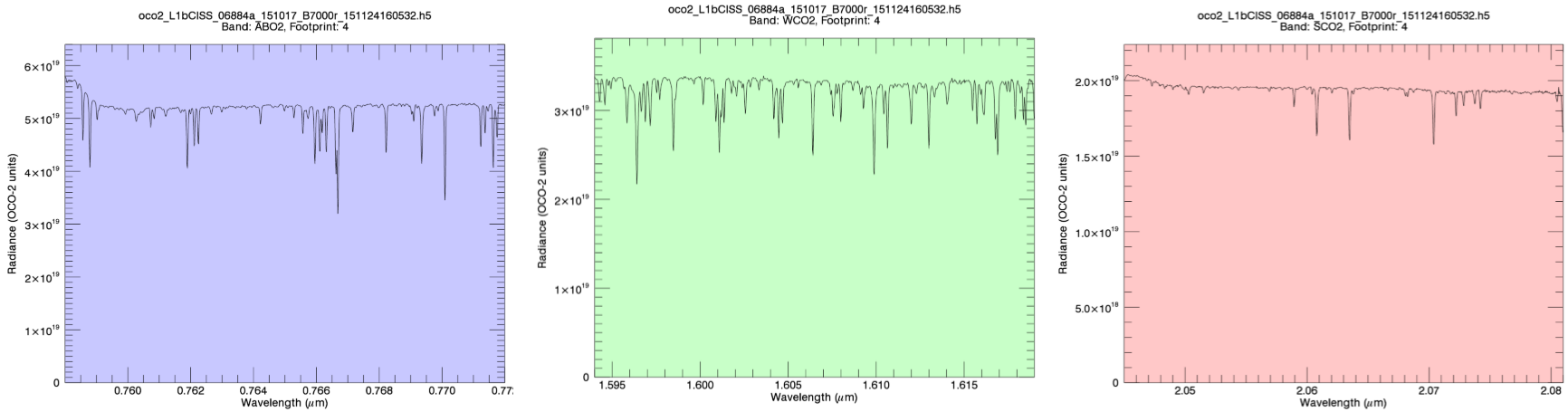
- OCO-2 observes the sun through a solar diffuser to collect solar spectra for radiometric and spectroscopic calibration

- Solar Doppler calibration
  - With solar diffuser in place, the instrument is pointed at the sun and the solar spectra are acquired through the entire daylight side of an orbit
  - This operation collects thousands of spectra with Doppler shifts of +/- 7 km/sec



Solar Doppler Spectra

- Solar Doppler spectra from complete orbits can be Doppler-corrected, and mapped onto a common wavelength grid to produce a massively oversampled solar spectrum for each OCO-2 channel
- We now have 15+ Solar Doppler orbits



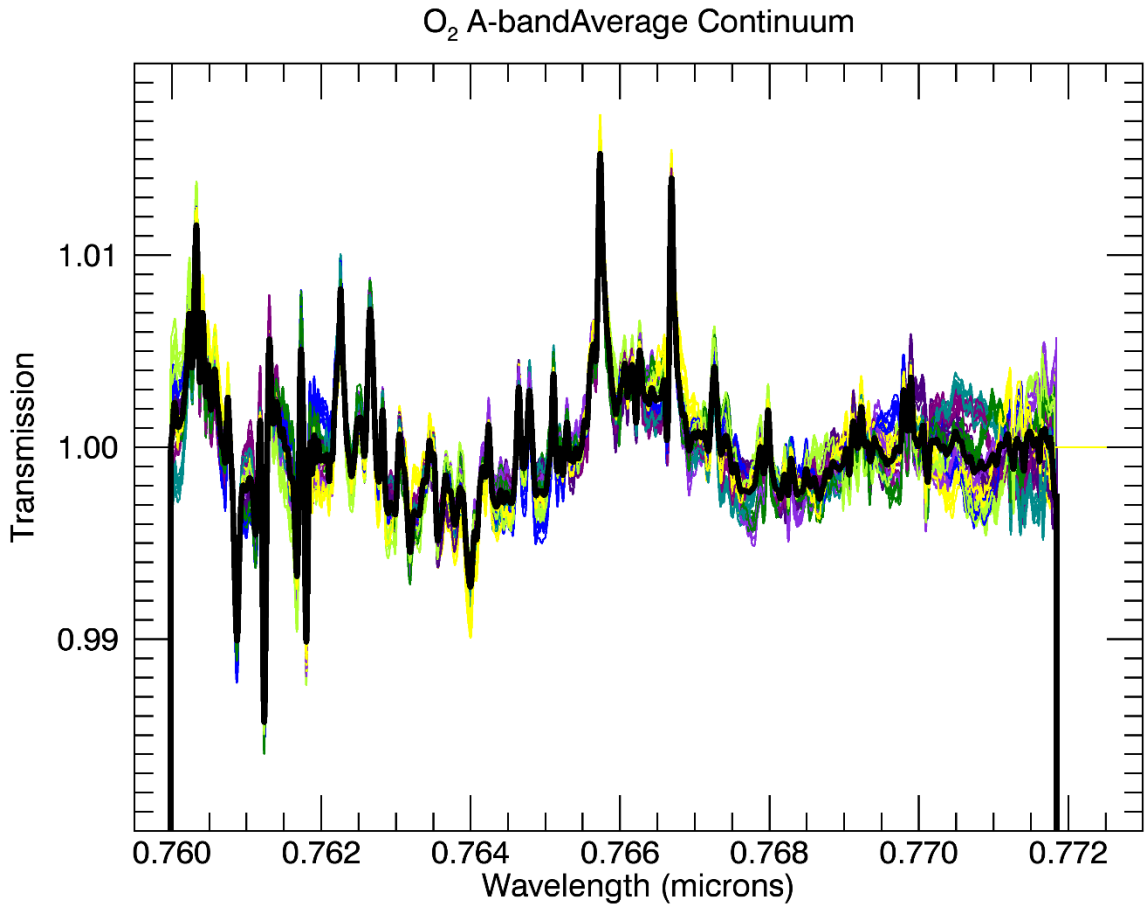
Raw Solar Doppler spectra collected in ABO2 (blue), WCO2 (green) and SCO2 channels.

Solar Doppler Residuals

- To compare these spectra to the solar spectrum used in the L2 algorithm(Toon, 2014/2016), each solar spectrum collected during a Solar Doppler orbit is:
  - normalized to unity
  - Subtracted an ILS-convolved, Doppler shifted, synthetic solar transmission spectrum that has been sampled appropriately by each FPA

- The resulting "residual spectra" for all footprints and all solar Doppler orbits were then corrected for solar Doppler shift, and mapped onto a common, high resolution spectral grid to produce a massively over-sampled solar residual spectrum
  - Here, we use a simple weighted average mapping algorithm to map the spectrum to the wavelength grid used for the input transmission spectrum used in the L2 algorithm

ABO2 Residuals (relative to Toon 2014)

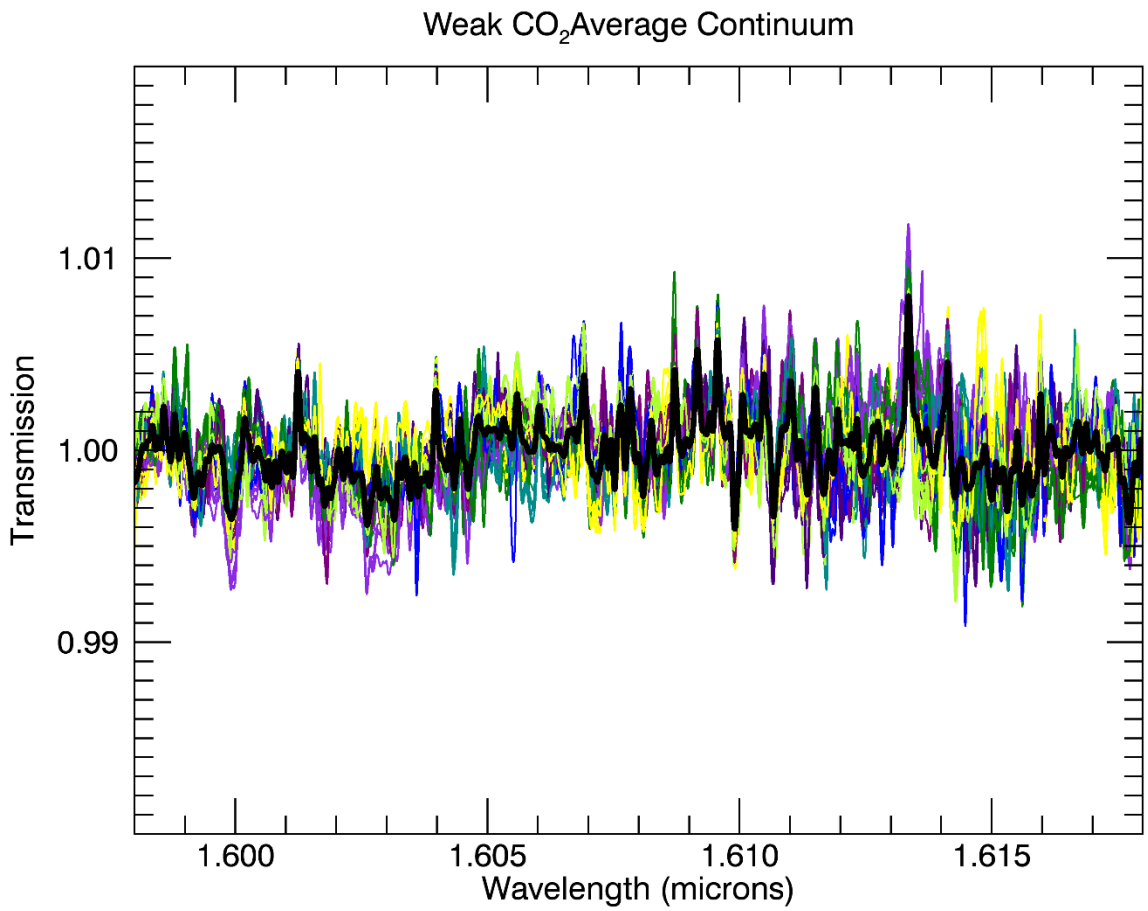


The different colors (in rainbow order from violet through yellow) indicate the different footprints.

The sharp spikes are due to errors in the synthetic solar spectrum.

Mean solar Doppler residuals for ABO2 (black line) compared to individual footprint results (colored lines) for orbits 1264-7670.

WCO2 Residuals (relative to Toon 2014)

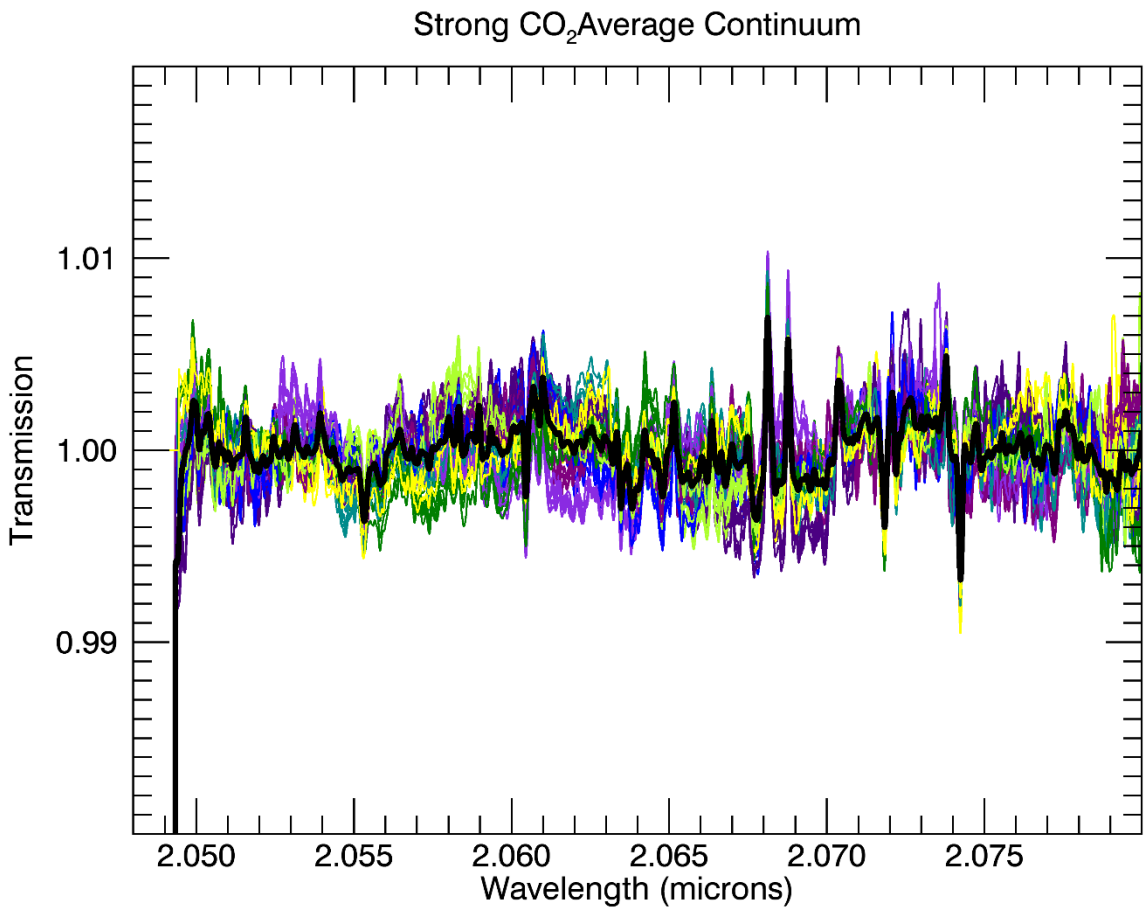


The different colors (in rainbow order from violet through yellow) indicate the different footprints.

There is significant footprint-to-footprint variability in the WCO2 residuals.

Mean solar Doppler residuals for WCO2 (black line) compared to individual footprint results (colored lines) for orbits 1264-7670.

SCO2 Residuals (relative to Toon 2014)

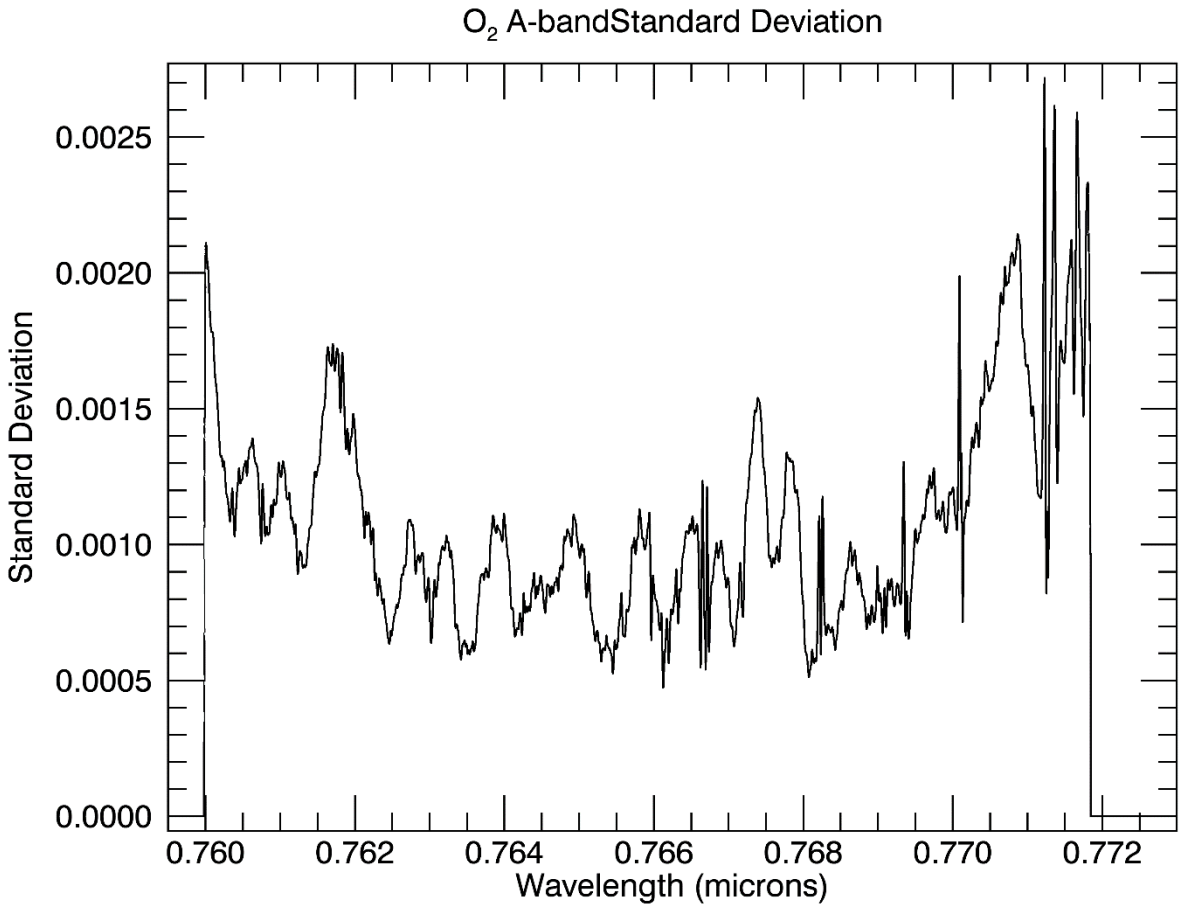


The different colors (in rainbow order from violet through yellow) indicate the different footprints.

There is significant footprint-to-footprint variability in the SCO2 residuals.

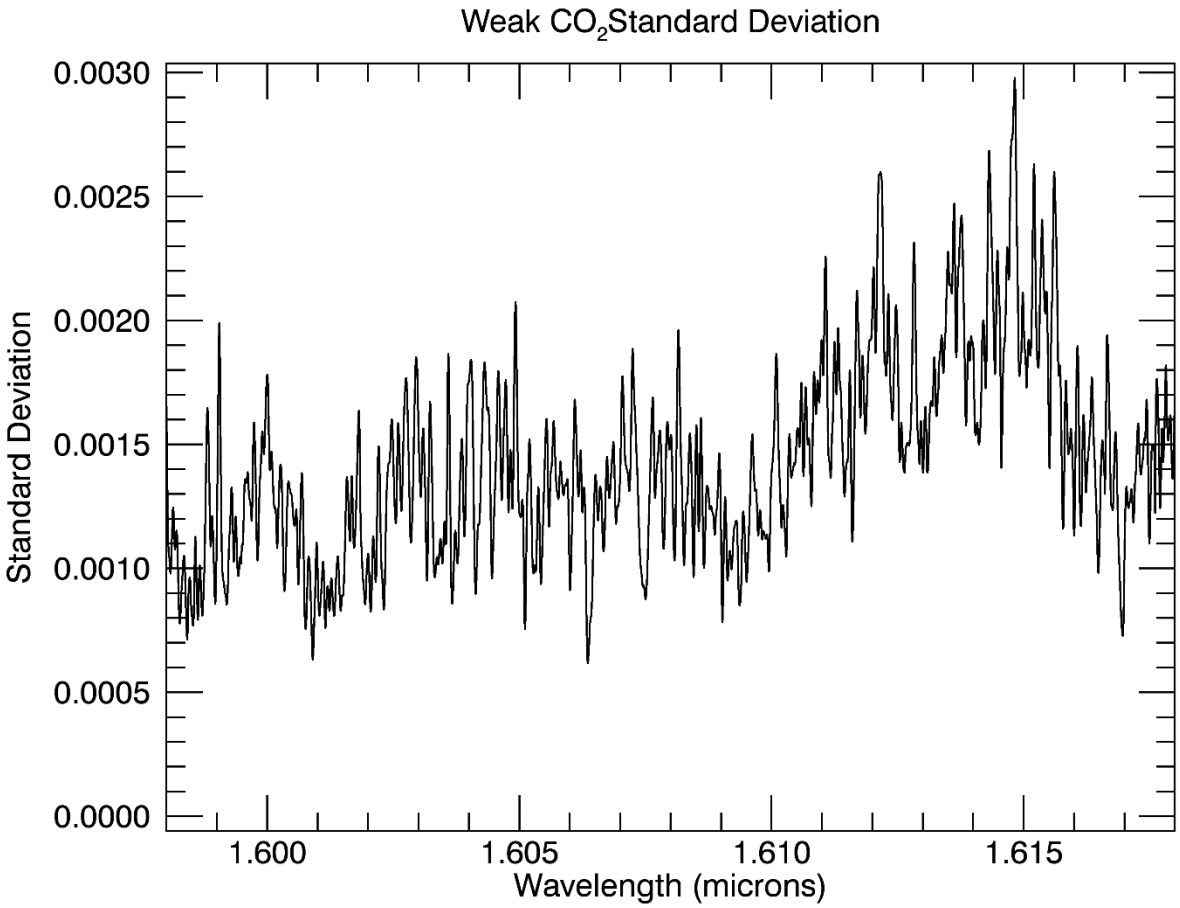
Mean solar Doppler residuals for SCO2 (black line) compared to individual footprint results (colored lines) for orbits 1264-7670.

ABO2 Standard Deviations



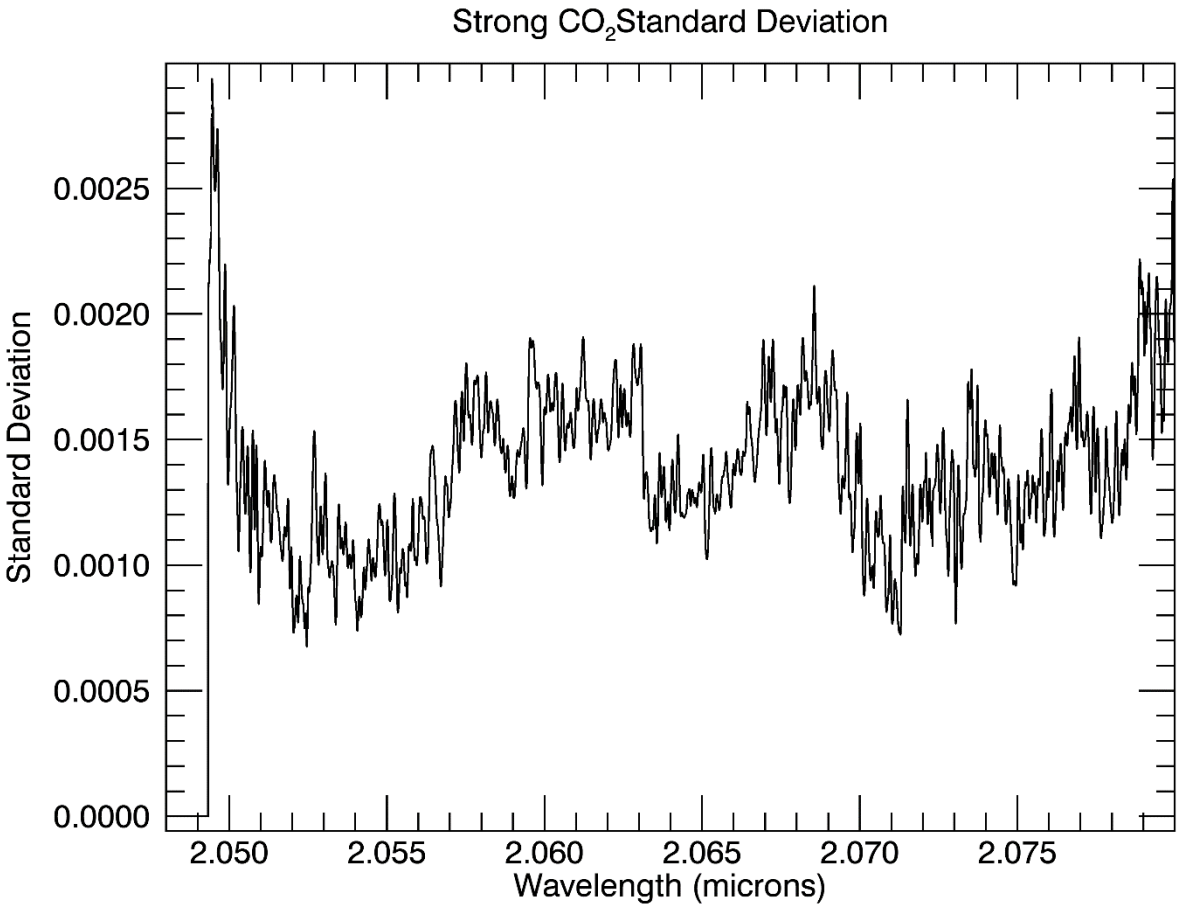
Solar Doppler footprint-to-footprint and orbit-to-orbit standard deviations for ABO2 for orbits 1264-7670.

WCO2 Standard Deviations



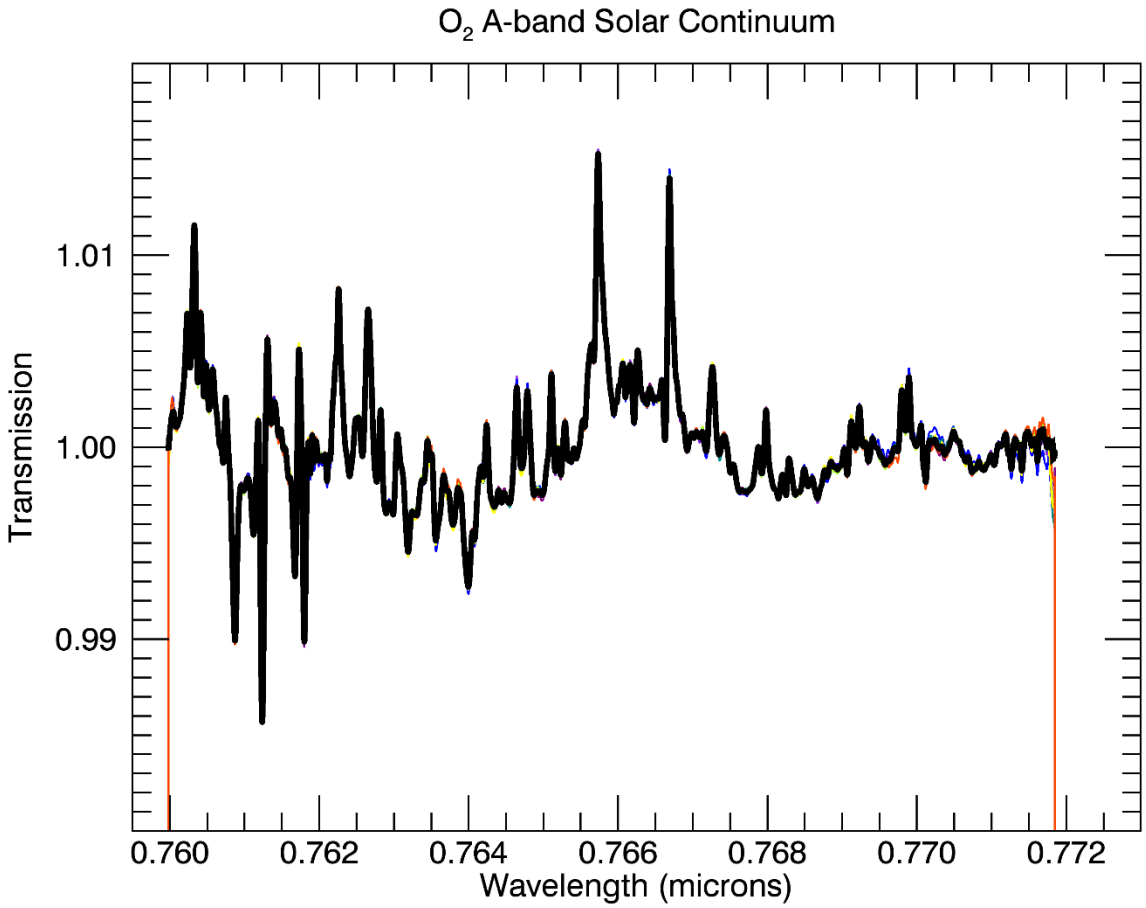
Solar Doppler footprint-to-footprint and orbit-to-orbit standard deviations for WCO2 for orbits 1264-7670.

SCO2 Standard Deviations



Solar Doppler footprint-to-footprint and orbit-to-orbit standard deviations for SCO2 for orbits 1264-7670.

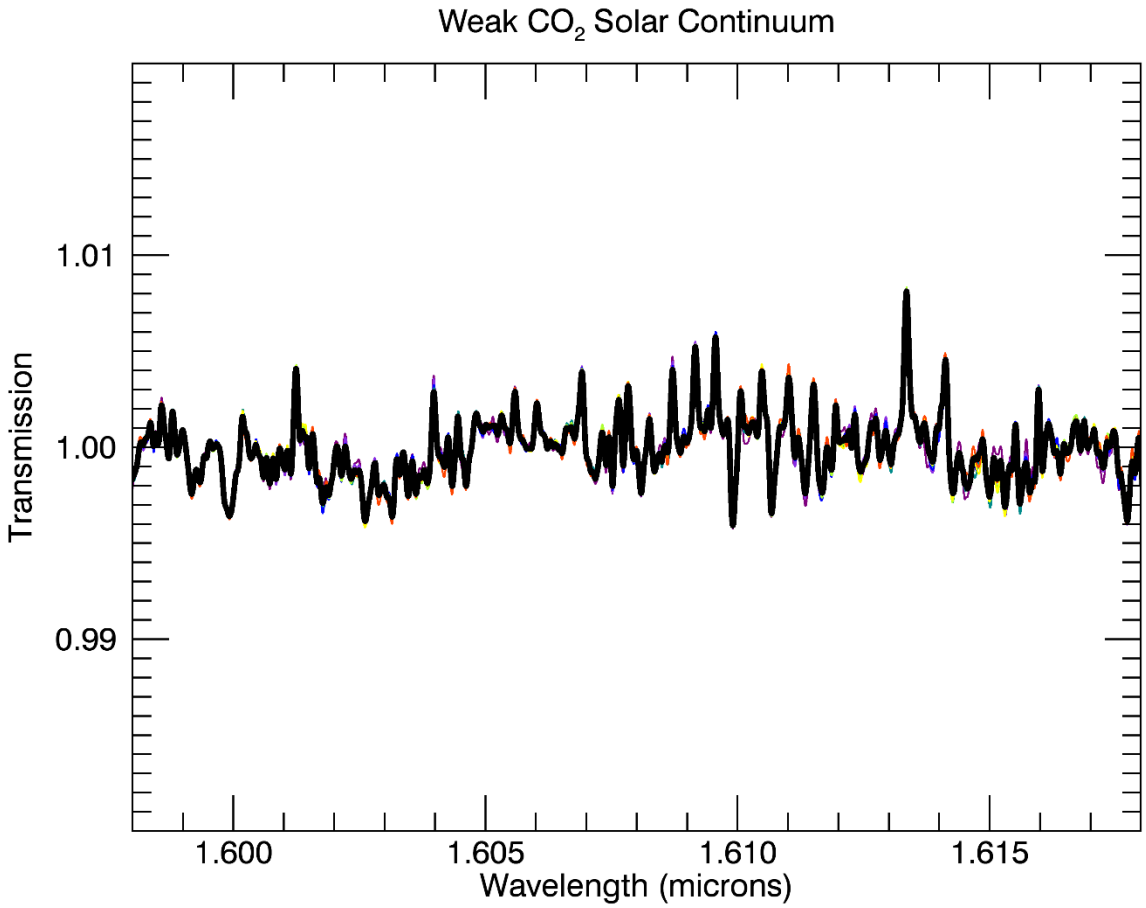
Mean ABO2 Residuals



Orbit-to-orbit variations in the mean residuals are much smaller than the footprint-to-footprint variations => Stability

Mean ABO2 solar Doppler residuals (black line) for orbits 1264-7670 compared to means for individual solar Doppler orbits(colored lines).

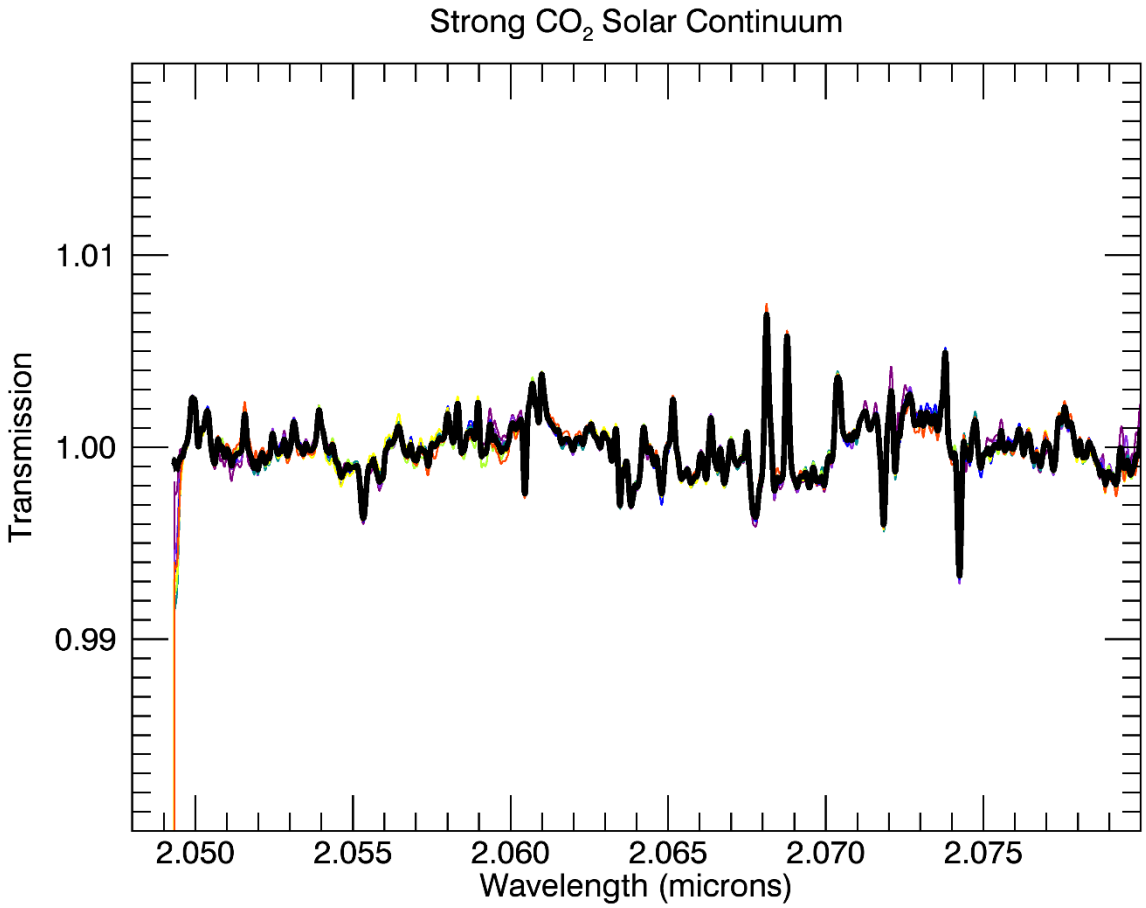
Mean WCO2 Residuals



Orbit-to-orbit variations in the mean WCO2 residuals are probably associated with imperfectly corrected bad pixels

Mean WCO2 solar Doppler residuals (black line) for orbits 1264-7670 compared to means for individual solar Doppler orbits(colored lines).

Mean SCO2 Residuals

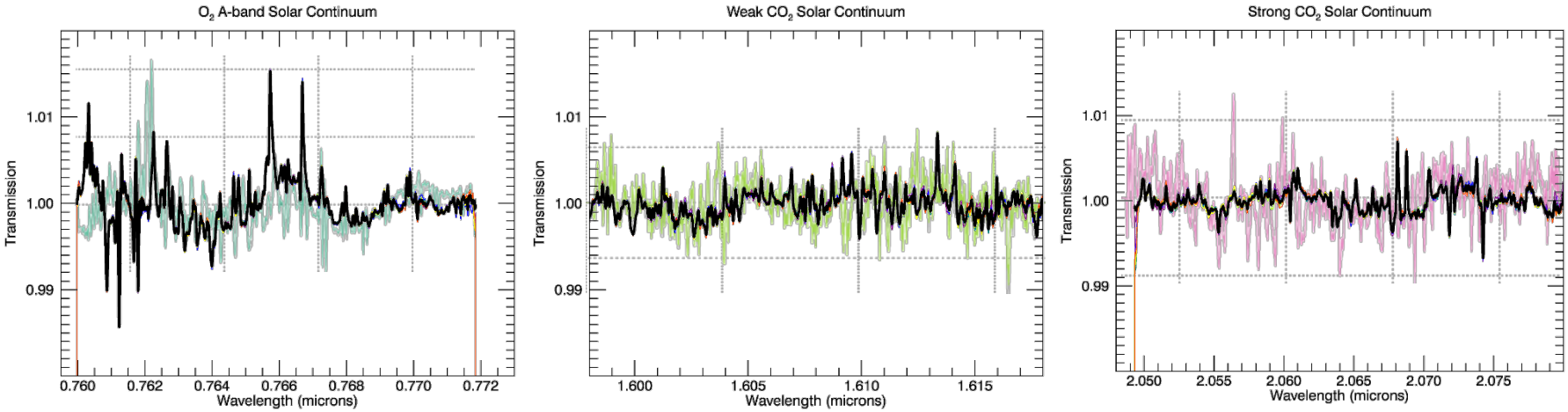


Orbit-to-orbit variations in the mean SCO2 residuals are probably associated with imperfectly corrected bad pixels

Mean SCO2 solar Doppler residuals (black line) for orbits 1264-7670 compared to means for individual solar Doppler orbits(colored lines).

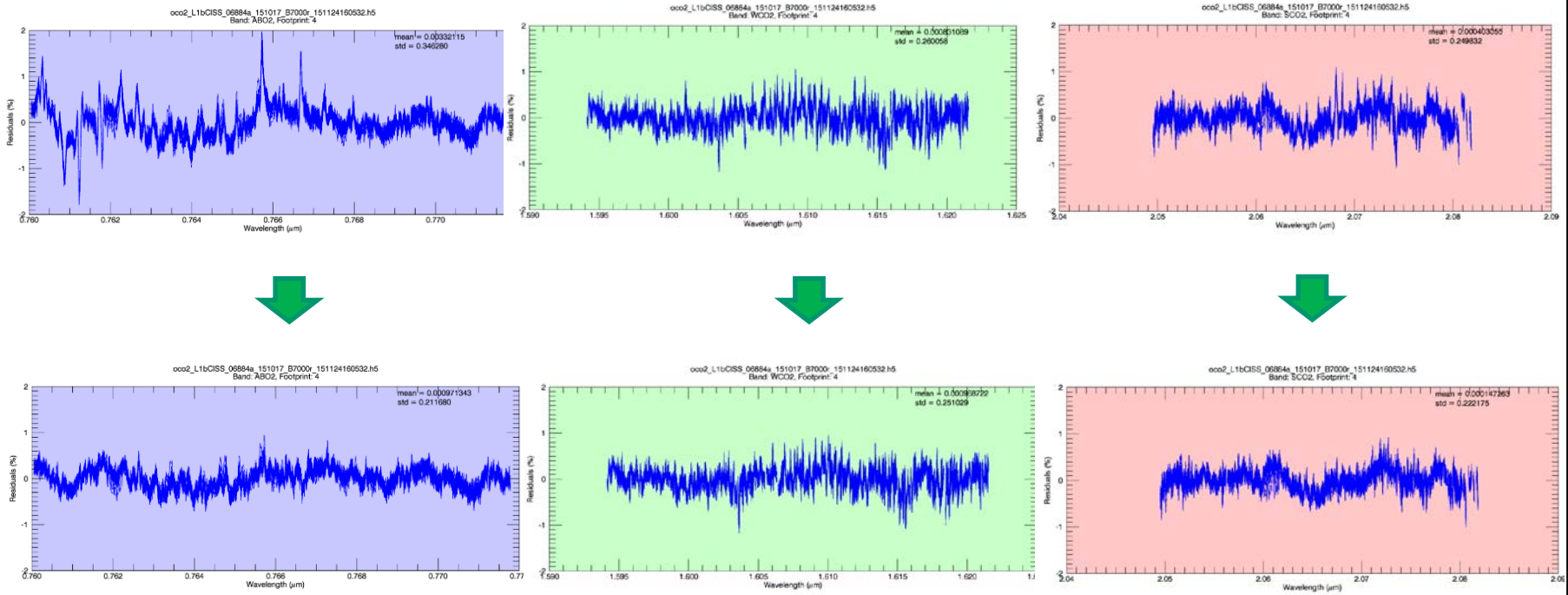
Revised Solar Line List and Continuum

- Empirical fits to the Solar Doppler data reduce spectral residuals
- Impact on X_{CO2} retrievals under investigation
  - Should reduce solar contributions to EOF's



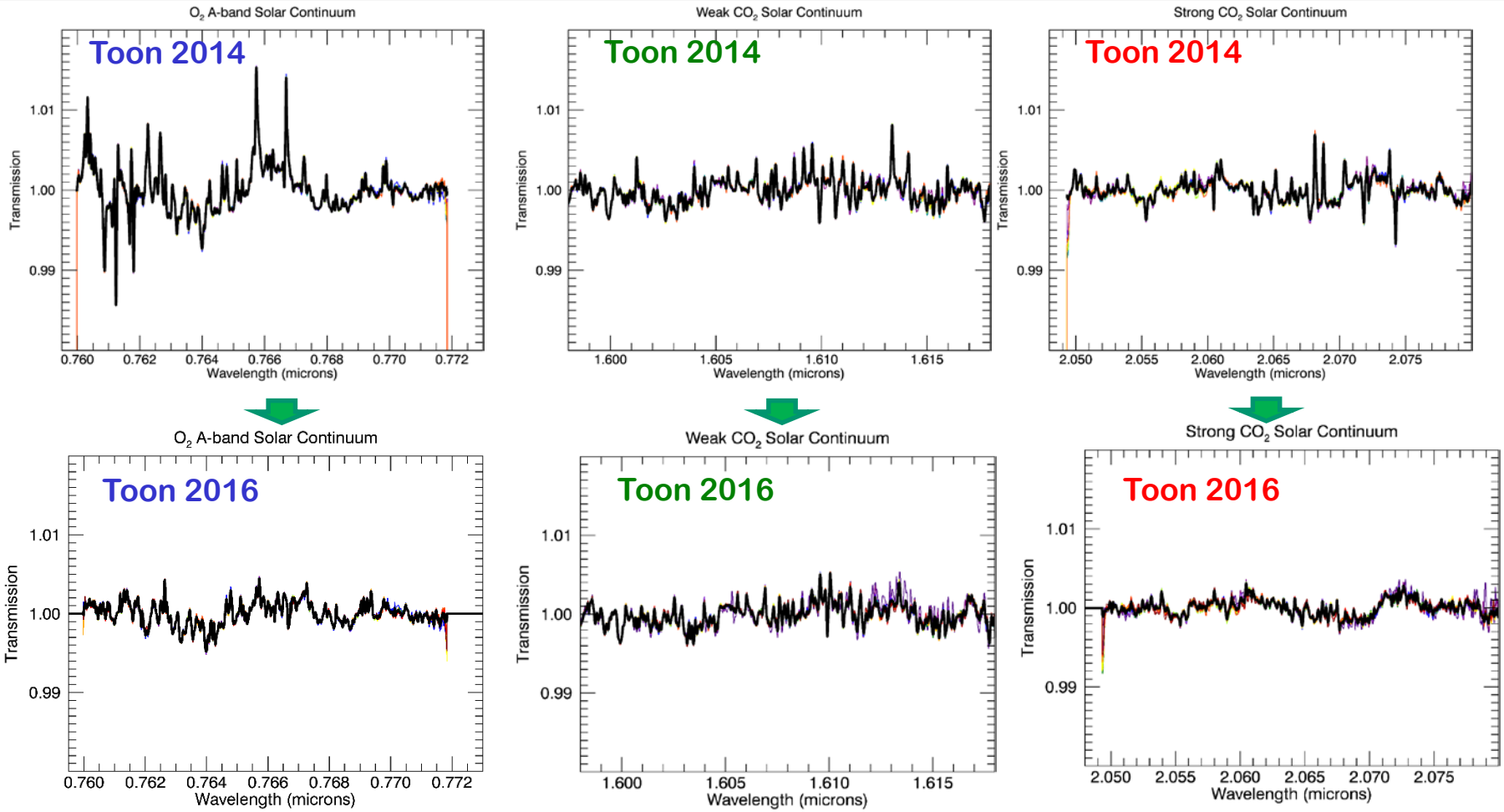
Empirical corrections to solar continuum based on 11 Solar Doppler Calibration tests (black lines) account for much of the structure seen in v7 EOF#1 (colored lines).

Revised Solar Line List (Toon 2016)



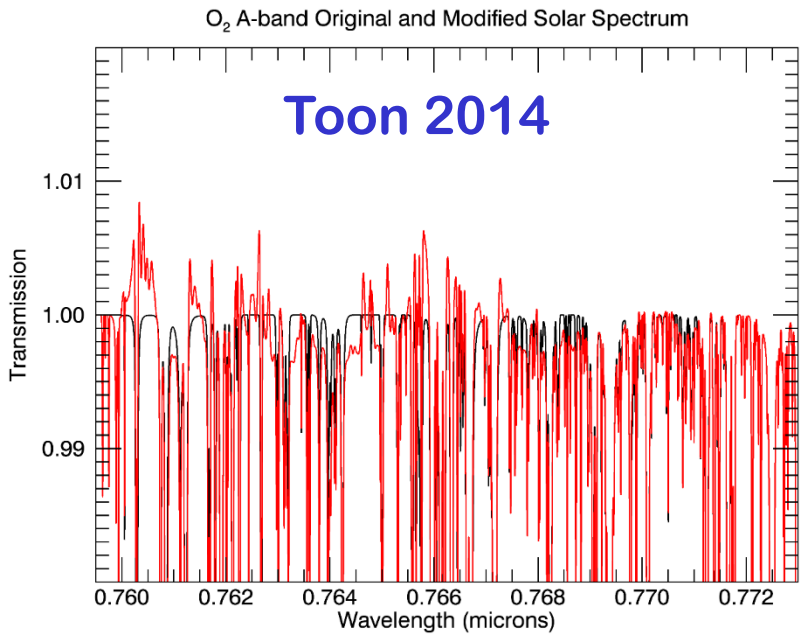
Recent improvements in the solar line list explain many of the most persistent spectral residuals seen in the solar spectra

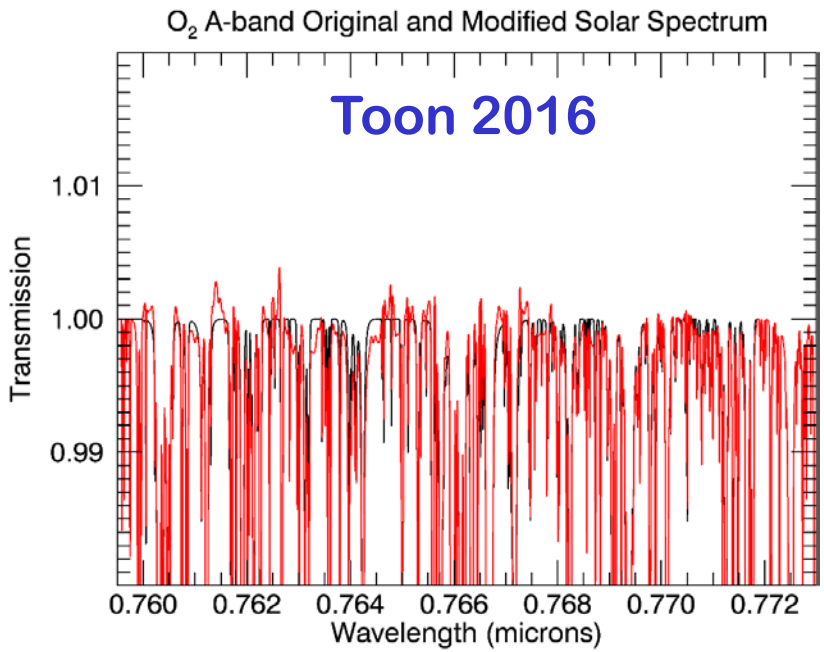
Reduced Solar Doppler Residuals for Updated Solar Line List



Continuum corrections are smaller for Toon (2016) than those for Toon (2014), reflecting improvements in the synthetic solar spectrum.

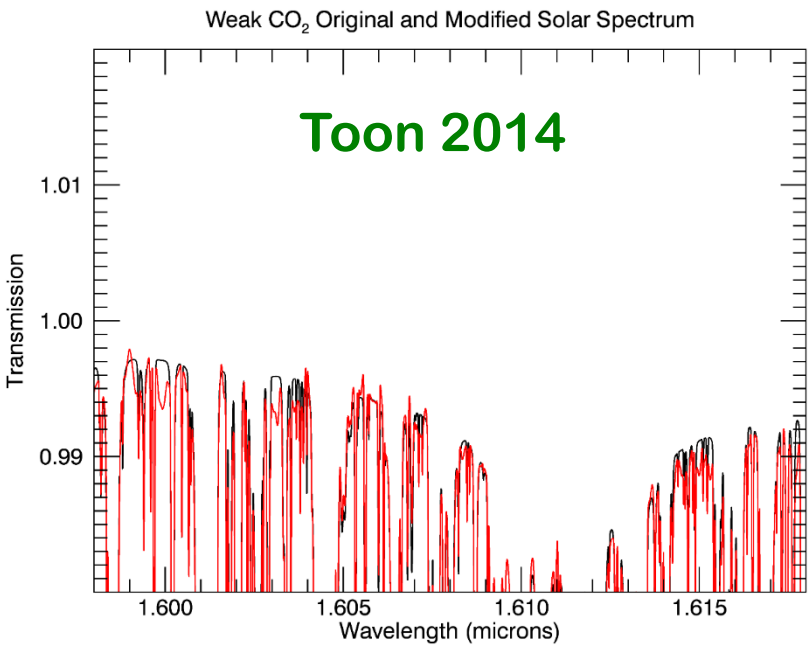
Modified ABO2 Solar Spectrum

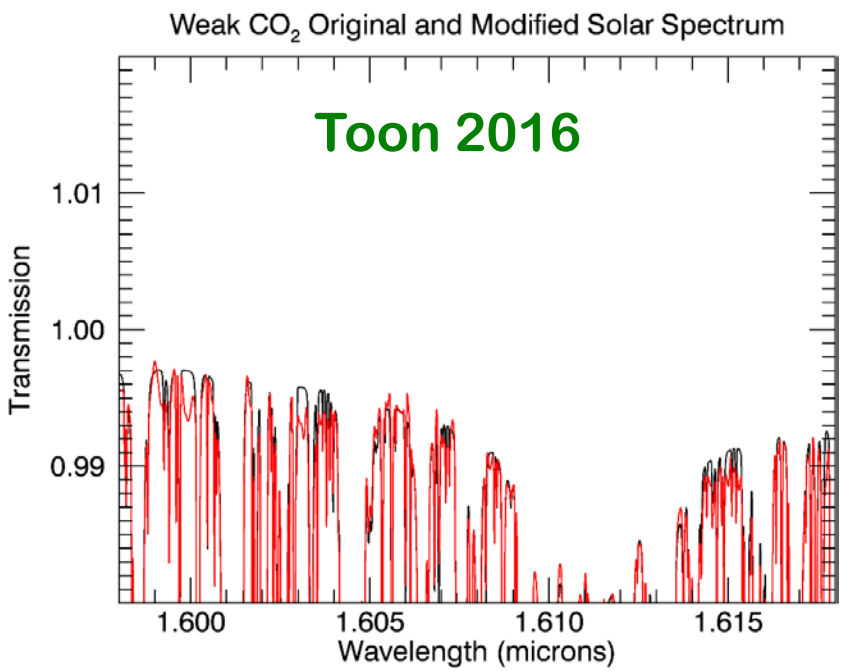




The mean solar Doppler continuum (red) procures substantial changes in the baseline ABO2 solar transmission spectrum for the older synthetic spectra (black, Toon 2014), but smaller changes for the updated spectrum

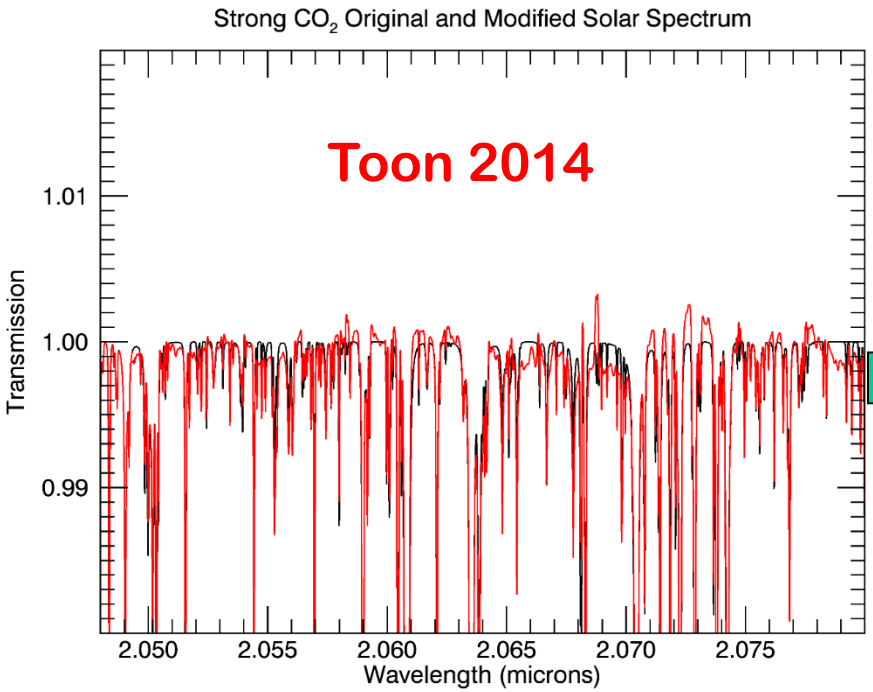
Modified WCO2 Solar Spectrum

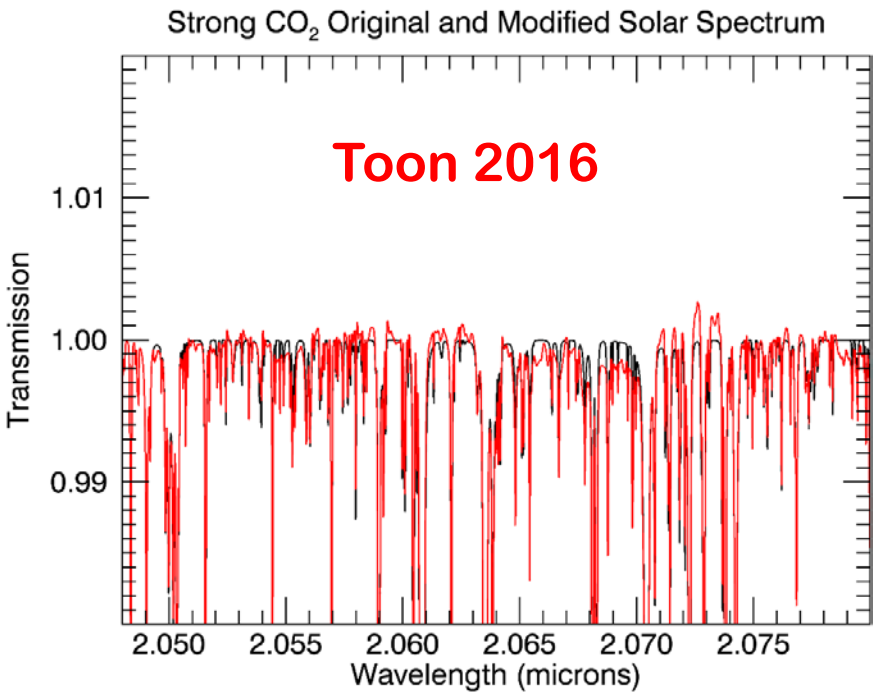




The mean solar Doppler continuum (red) produces on minor changes to the baseline WCO2 solar spectrum (black).

Modified SCO2 Solar Spectrum

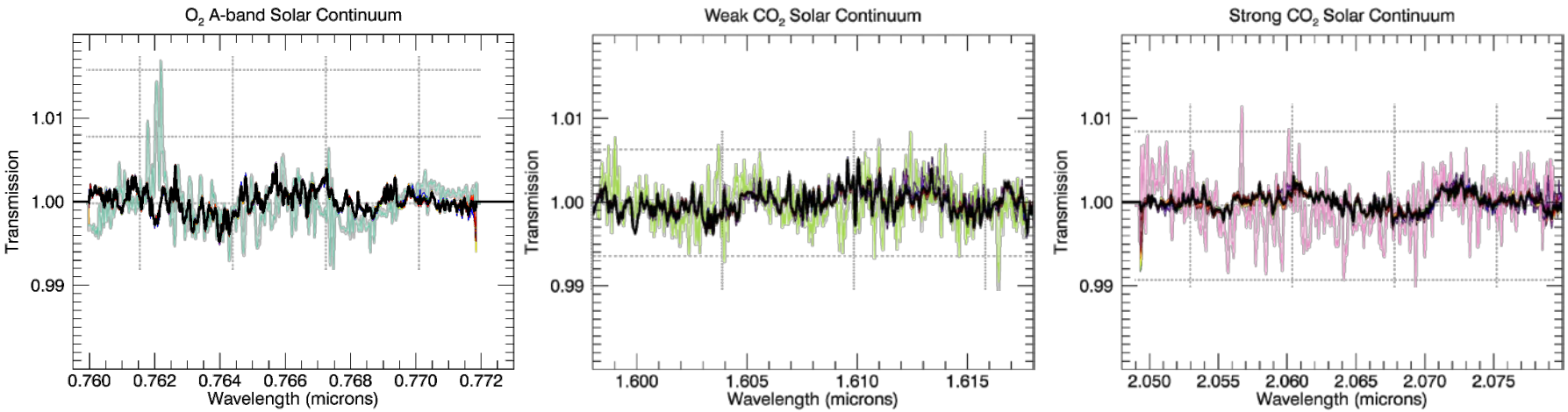




The mean solar Doppler continuum (red) produces only minor modifications to the baseline SCO2 solar spectrum (black).

Solar Doppler Residuals vs EOF(1)

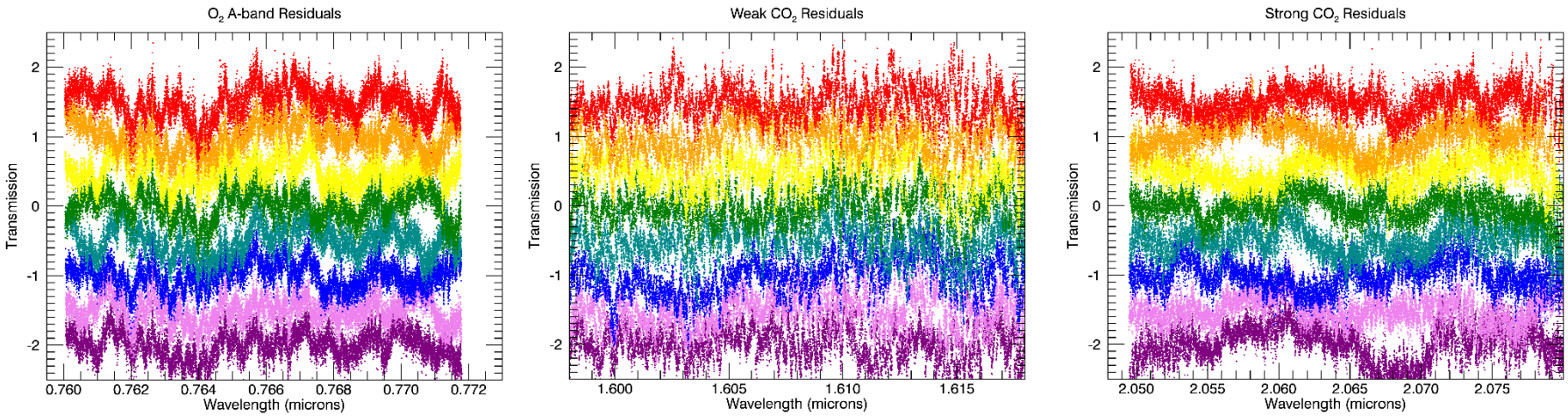
- The revised corrections to the solar continuum model retain many of the most pronounced features of EOF(1)
- The EOF's will now be needed primarily to correct
  - Footprint-to-footprint variations in the radiometric calibration
  - Remaining errors in the gas absorption coefficients



Empirical corrections to solar continuum based on 11 Solar Doppler Calibration tests (black lines) account for much of the structure seen in v7 EOF#1 (colored lines).

Primary Issue: Footprint-to-Footprint Variations

- Footprint-to-footprint variations in the recorded solar spectra now dominate the Solar Doppler residuals.
- These variations are most likely due to small (< 0.25%) errors in the radiometric calibration.



The spectral residuals for each footprint for Solar Doppler Orbit 3898 have been offset by 0.5% to show the spectrally dependent variations.

Conclusions

- The mean solar Doppler residuals in OCO-2 solar Doppler orbits 1264 to 7640 are similar to those seen in GOSAT spectra and indicate subtle errors in the solar spectrum

- Persistent wavelength-dependent footprint-to-footprint variations in the solar Doppler residuals indicate that there are subtle (< 0.25%) errors in the footprint-to-footprint radiometric calibration

- While there is substantial footprint-to-footprint variation in the Solar Doppler residuals, there is very little variation the mean residuals for orbits 1264 and 7670

- The mean solar Doppler residuals account for the large scale structure of EOF #1 in the ABO2 band, and somewhat less of the structure of EOF #1 in the WCO2 and SCO2 bands