# ESLAB-52
# 14-May-2018

# Thermospheres of Terrestrial Planets Including Coupling with the Lower Atmosphere

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# Outline of Talk

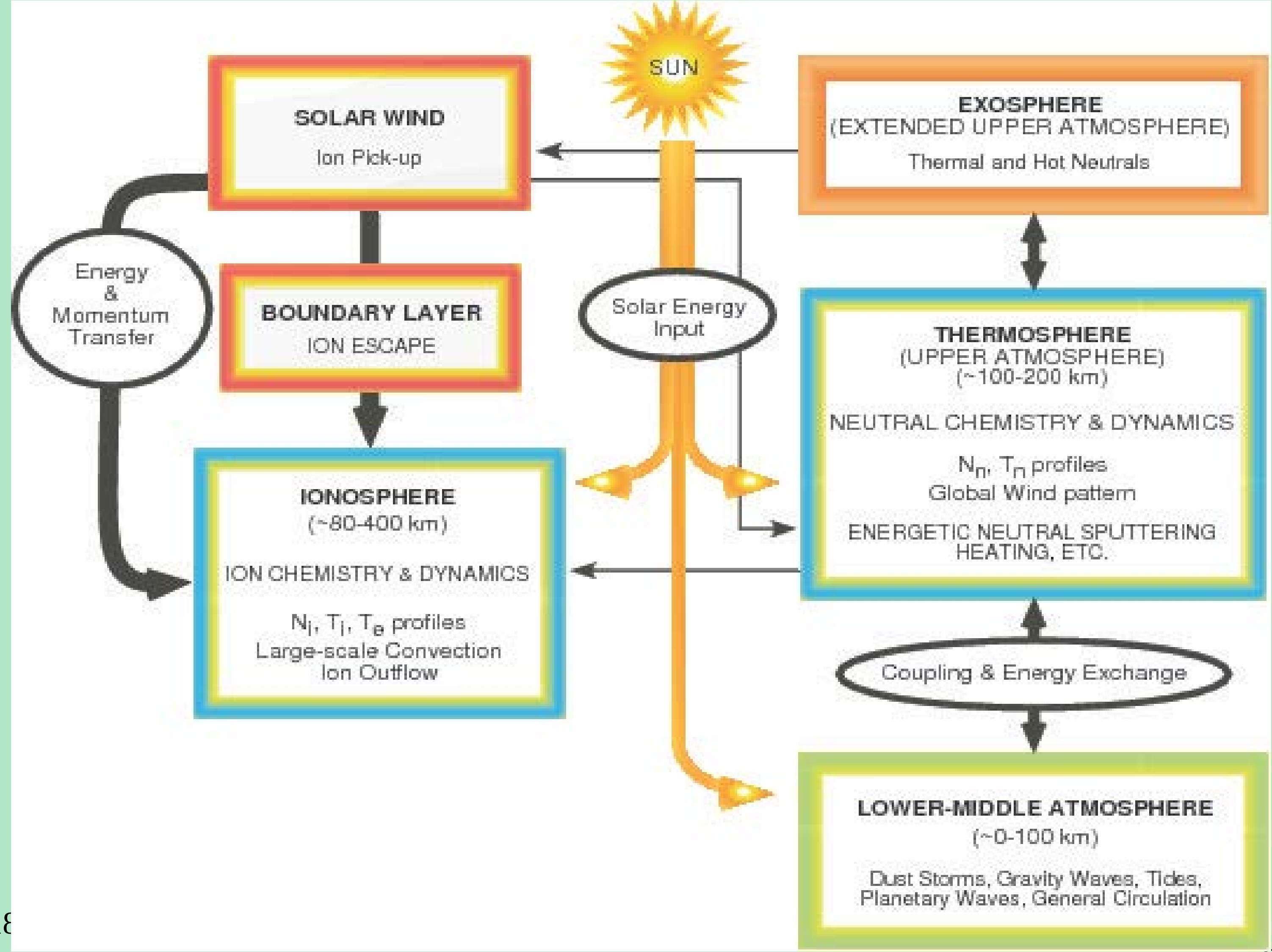
- ❑ Basic Thermospheric Features and P. Parameters
- ❑ Three Common Features and Processes to Contrast
  * Venus and Mars NO nightglow distributions as a tracer of UATM winds (proxy view of global circulation patterns).
  * Wind induced diffusion and Helium distributions
  * Day thermal budgets and relative roles of $CO_2$ 15-μm cooling, molecular thermal conduction and global winds
- ❑ Lower to Upper Atmosphere Coupling
  * Migrating and non-migrating tides of Mars vs Earth (densities, nightglow)
  * Homopause altitudes and eddy diffusion $K_{zz}$ for Mars vs Earth
  * Dust storms on Mars (regional storm impacts)
  * In-situ Mars thermospheric wind measurements (non-solar forcing)
  * Gravity waves at Venus (see talk by A. Brecht)

# Basics Thermospheric Features and Planetary Parameters

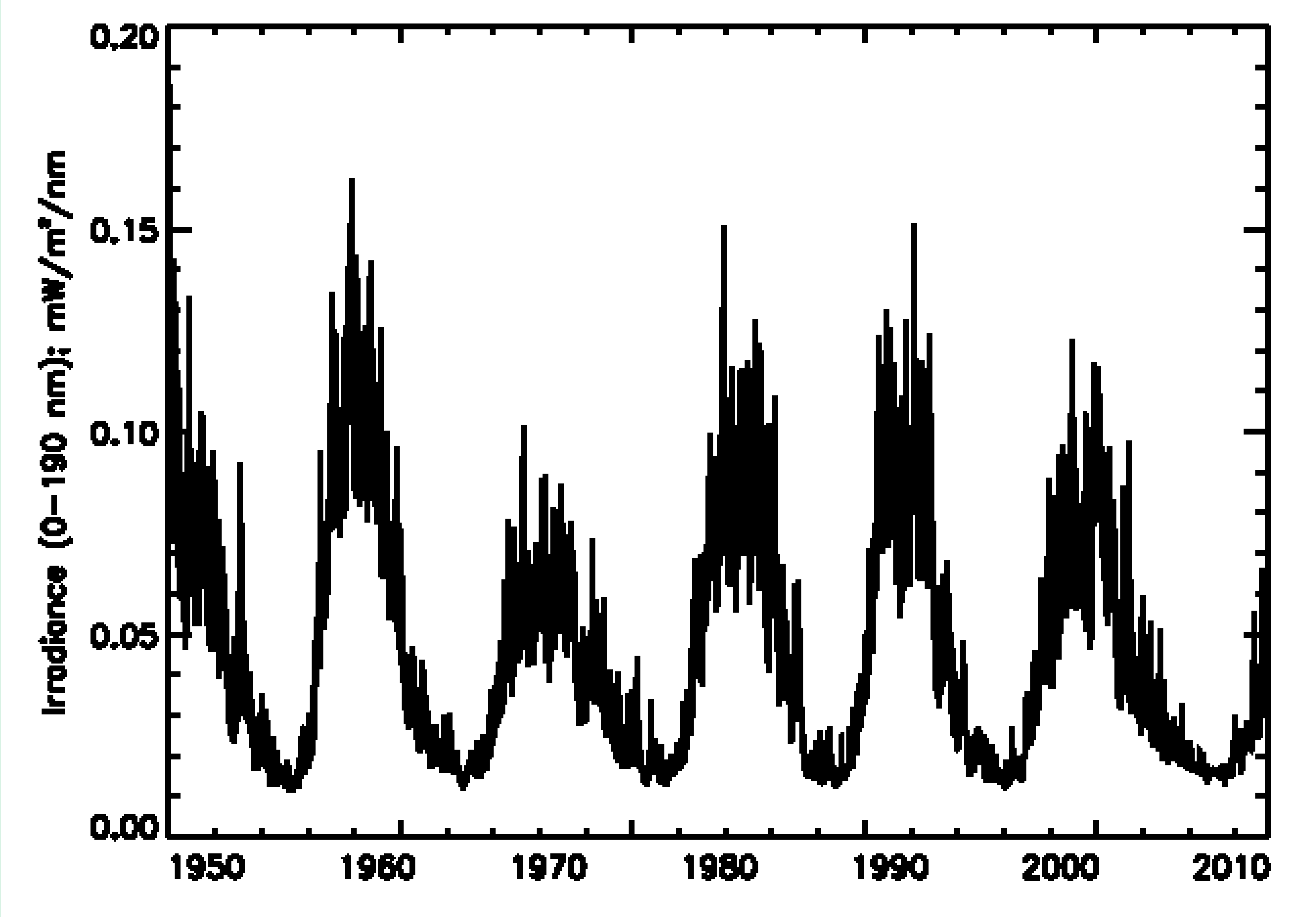
# Fundamental Planetary Parameters: Some Implications

| Parameter | Venus | Earth | Mars |
|---|---|---|---|
| Gravity ($cm^2/sec$): H(km) | 888 [4-12] | 982 [10-50] | 373 [8-22] |
| Heliocentric distance (AU) | 0.72 | 1.0 | 1.38-1-67 |
| Radius (km) | 6050 | 6371 | 3390 |
| Omega (rad/sec): Coriolis | 3.0(-7) [no] | 7.3(-5) [yes] | 7.1(-5) [yes] |
| Obliquity (deg): Seasons | 1-3 [no] | 23.5 [yes] | 25.12 [yes] |
| B-dipole moment (wrt Earth): Auroral/Joule heat | ≤4.0(-5) [no] | 1.0 [yes] | ≤2.5(-5) [no] Crustal fields |
| EUV-UV (eff.) | ~20% | 30-60% | ~20% |

# Mars (and Venus) Upper Atmospheric Regions and Processes (Bougher et al., 2015)

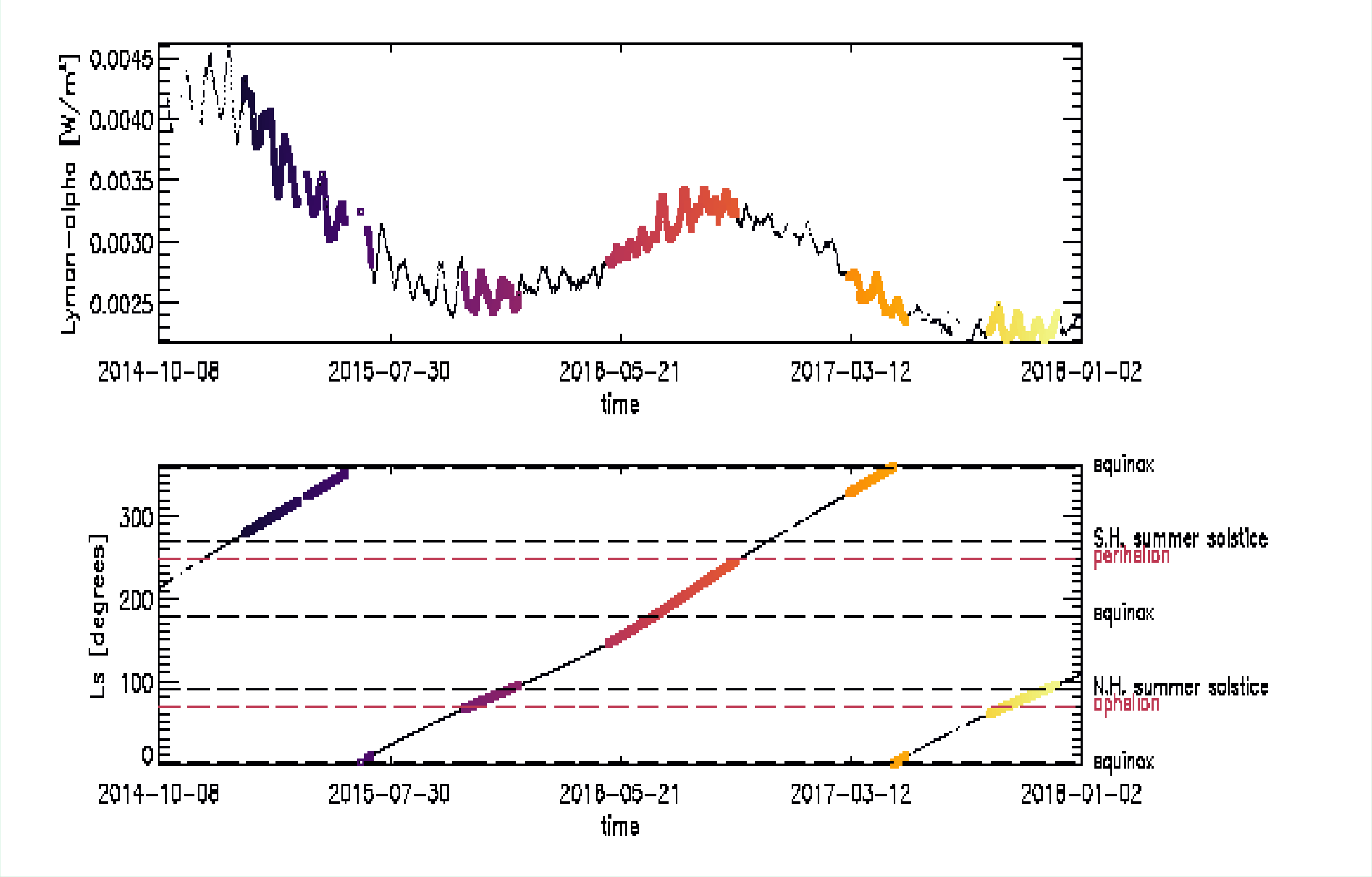


# Solar Spectral Irradiance Variations over the Solar Cycle (~0.1-190.0 nm)

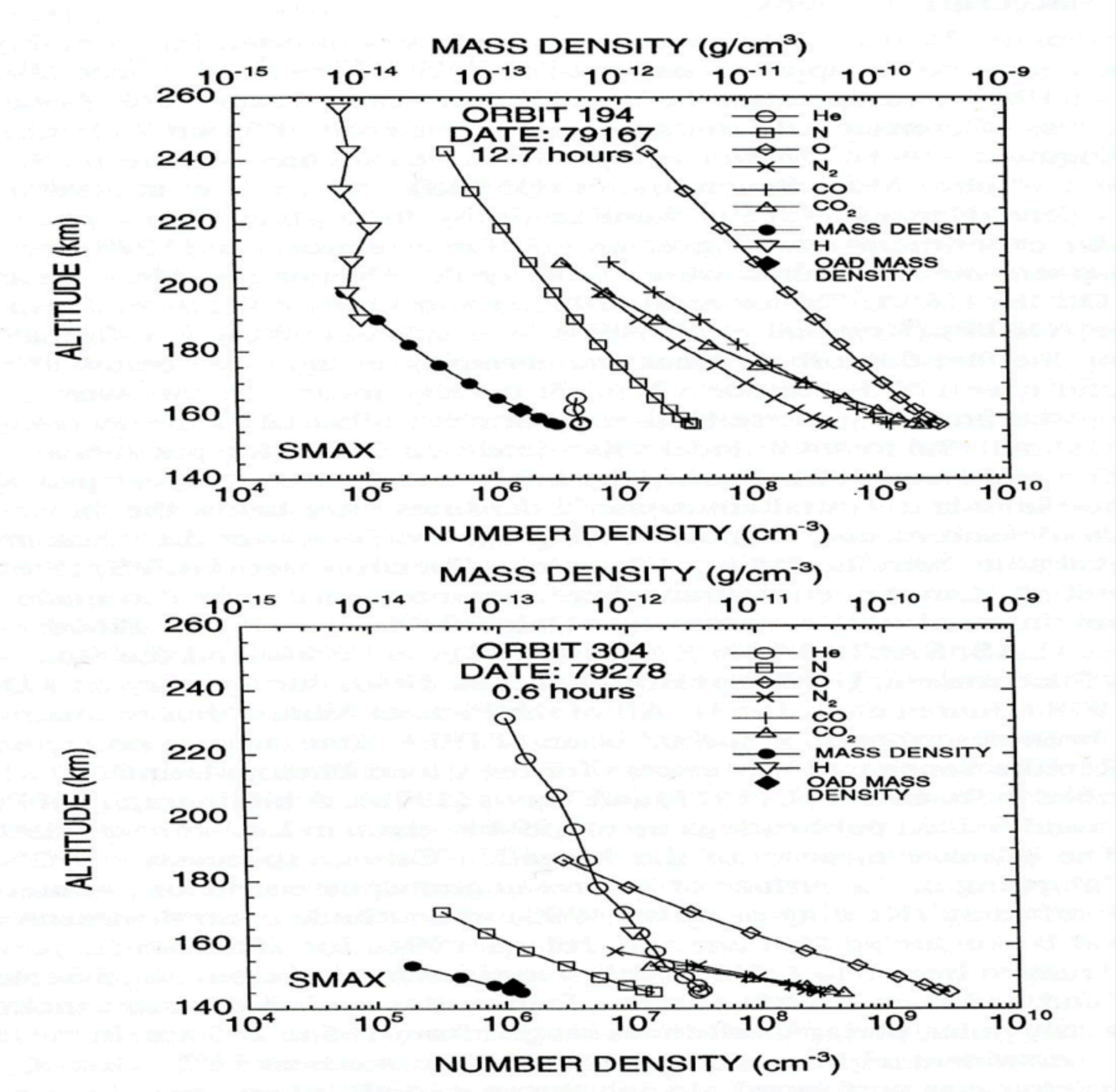



Integrated 0-190 nm FISM irradiance (1947-2011)

# Solar EUV Monitor at Mars: EUVM Instrument 3-Diodes and FISM-M Daily Averaged Fluxes (Pilinski et al 2018)



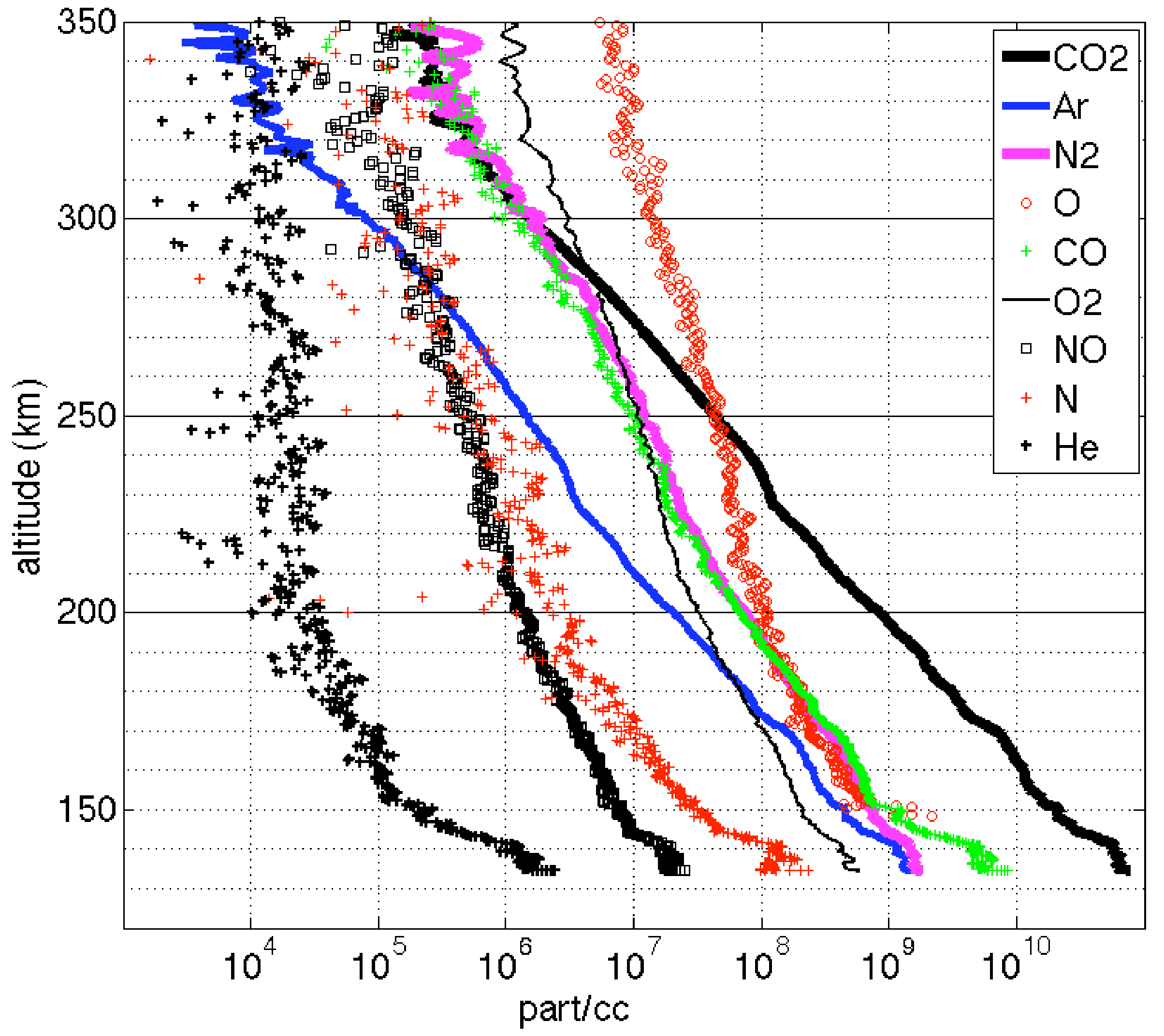
# Composition Differences : Venus Upper Atmosphere




## Venus

PVO/ONMS
Kasprzak et al (1997)
Venus II book

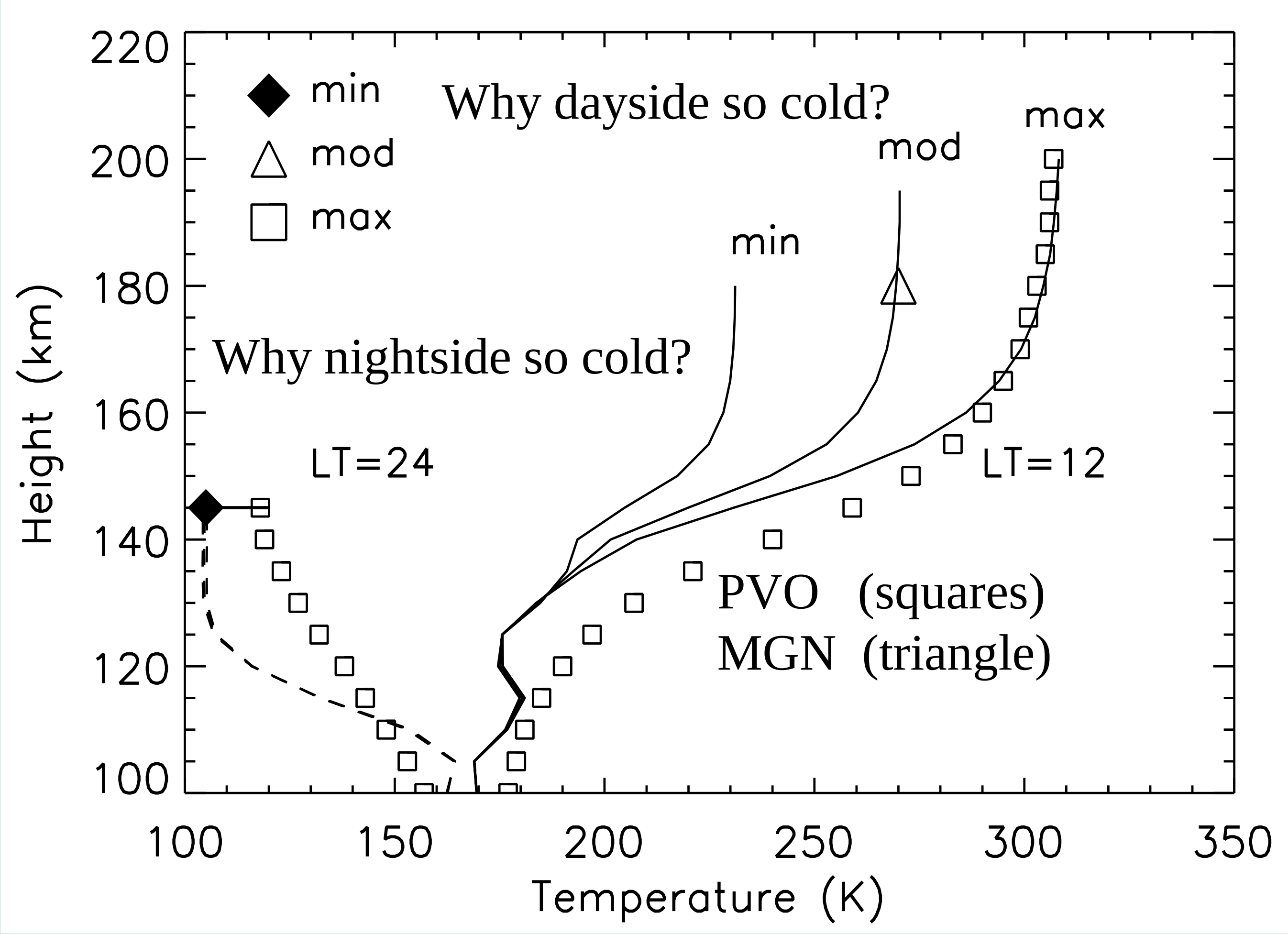
# Composition Differences : Mars Upper Atmosphere




## Mars

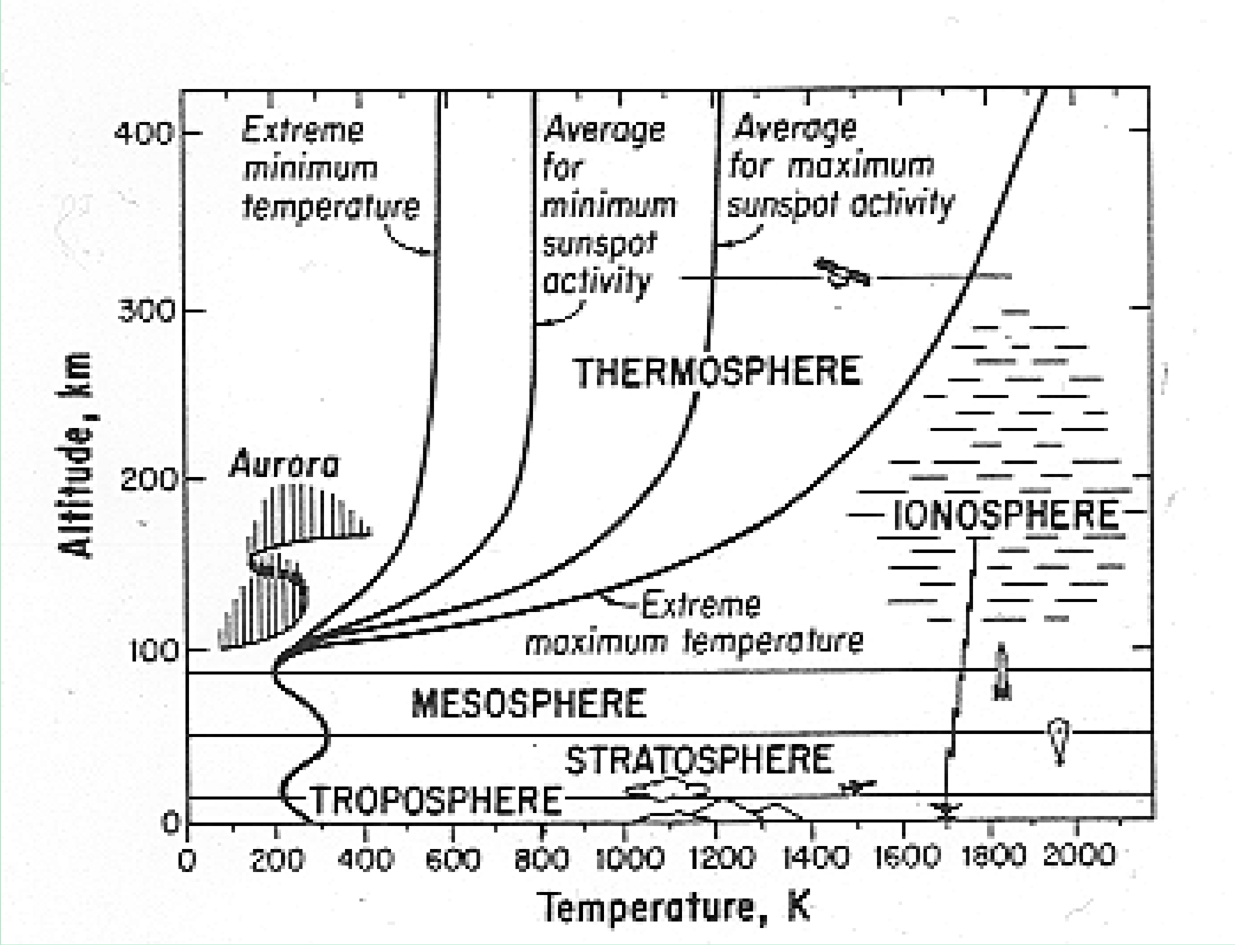
MAVEN/NGIMS
P1064, Ls ~ 256,
LT ~ 12PM, LAT = 4.5S
(Mahaffy et al. 2015.
GRL Special Issue)

# Thermospheric Temperature Profiles (1): Venus (Pioneer Venus and Magellan)



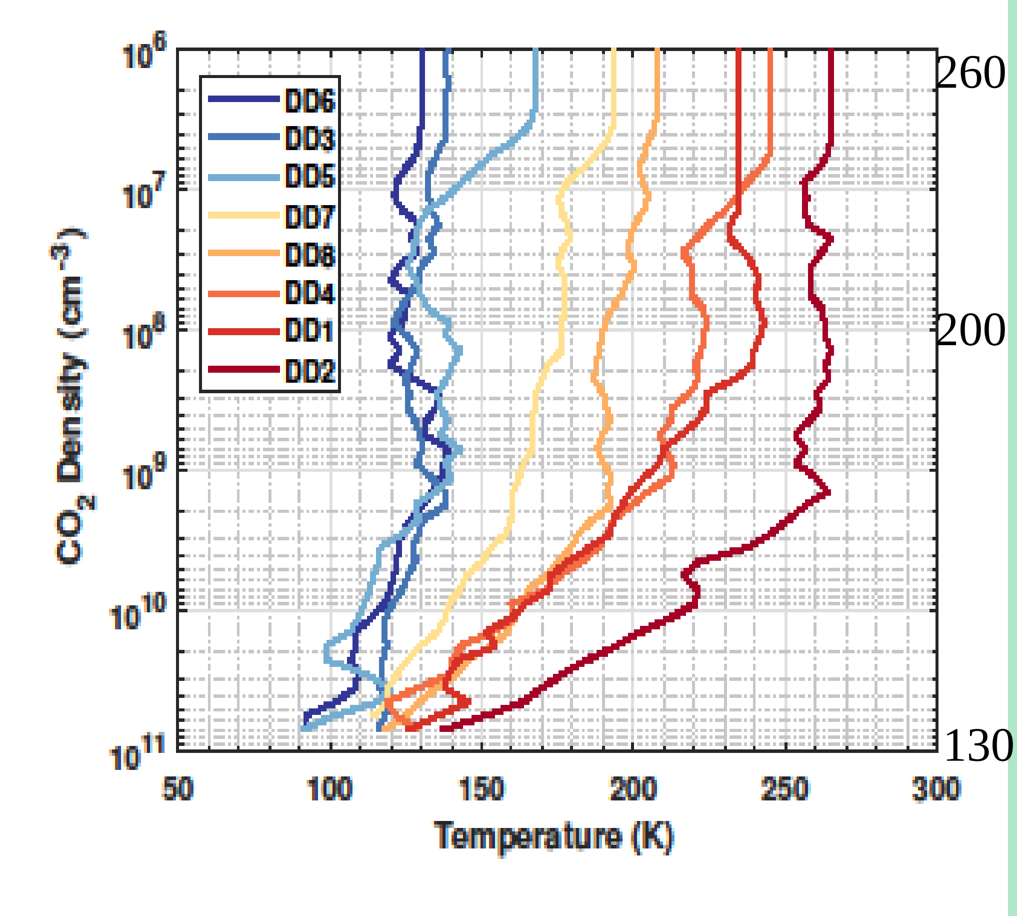

Bougher et al. (2002)

# Thermospheric Temperature Profiles (2): Earth




Adapted from Roble (1986)

# Thermospheric Temperature Profiles (3): Mars (MAVEN/NGIMS Deep Dips# 1-8)



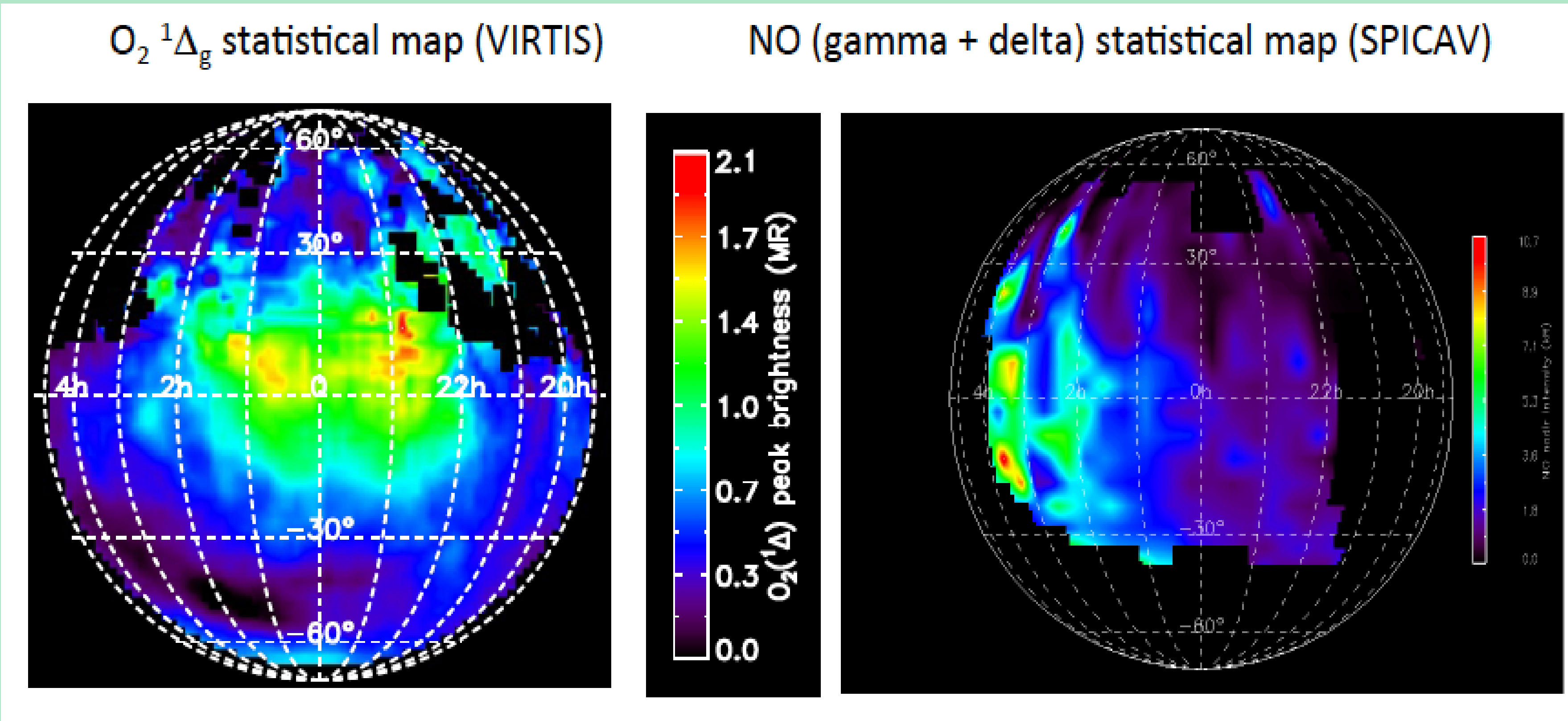

| DD | Ls | LT | LAT | SZA |
|---|---|---|---|---|
| 1 | 291 | 18.3 | 40-45N | 108 |
| 2 | 328 | 11.9 | 2-6S | 9 |
| 3 | 11 | 3.4 | 61-64S | 111 |
| 4 | 37 | 16.0 | 62-66S | 91 |
| 5 | 166 | 5.3 | 32-36N | 96 |
| 6 | 194 | 0.6 | 1-5S | 167 |
| 7 | 49 | 20-21 | 62-67N | ? |
| 8 | 76 | 13.5 | 5S-20N | 30 |

Stone et al. (2018) JGR

# Three Common Features and Processes to Contrast

# Statistical Maps of VEx $O_2$ and NO Nightglow Distributions:  ~100 km & 115 km layers

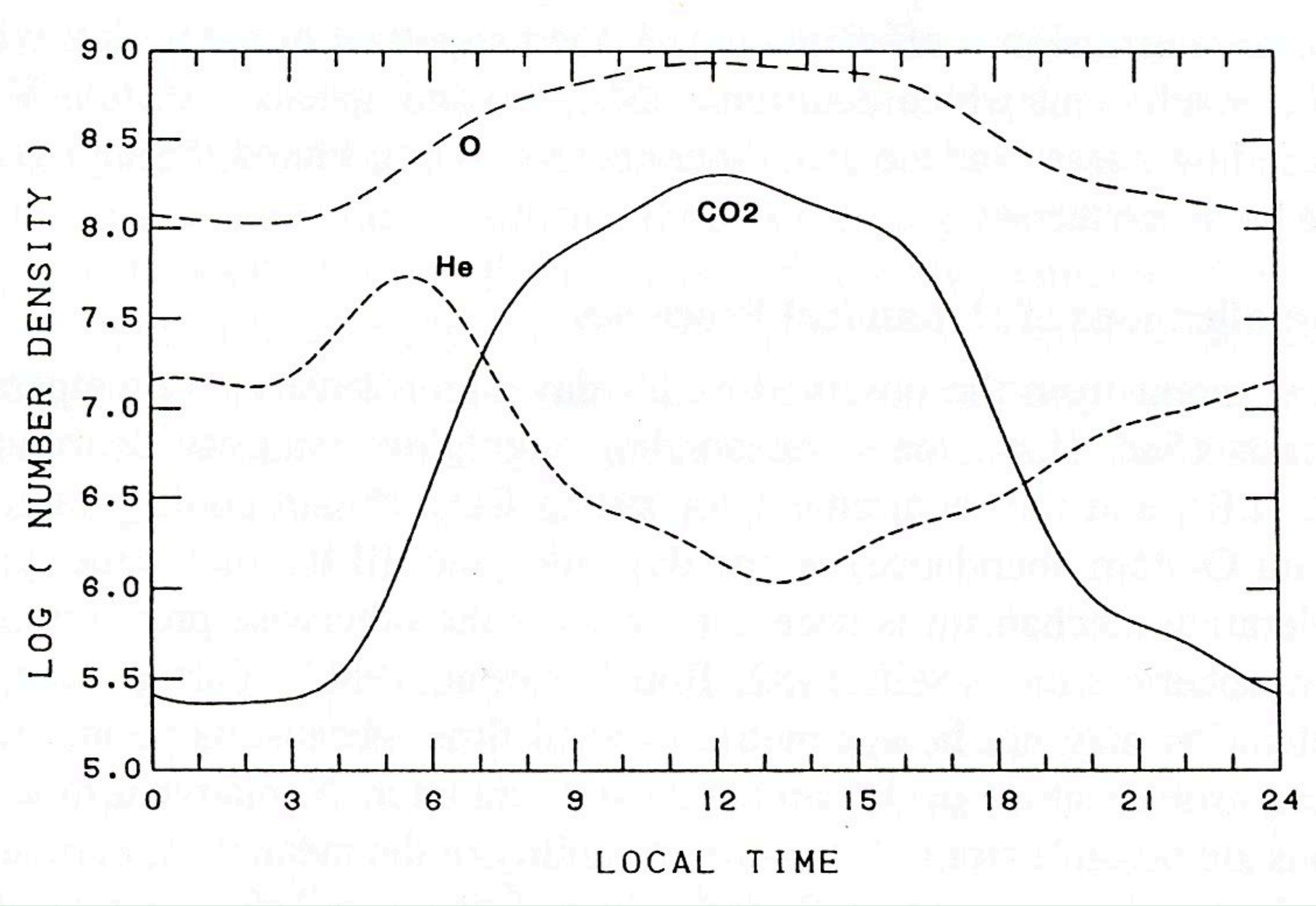
Soret et al., (2012); Stiepen et al. (2013); Gerard et al. (2018)



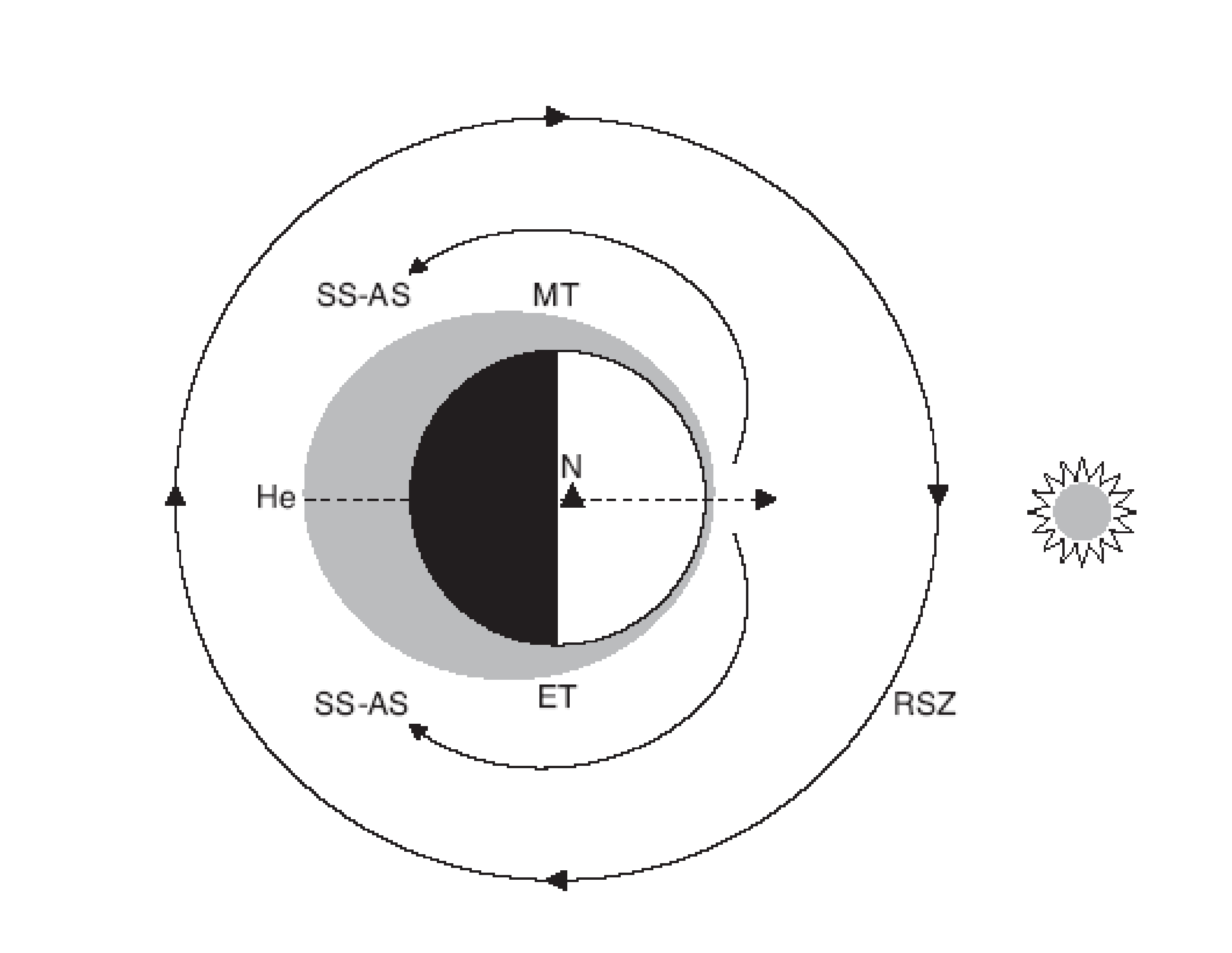

LT ~ 0 AM

LT ~ 2 to 4 AM

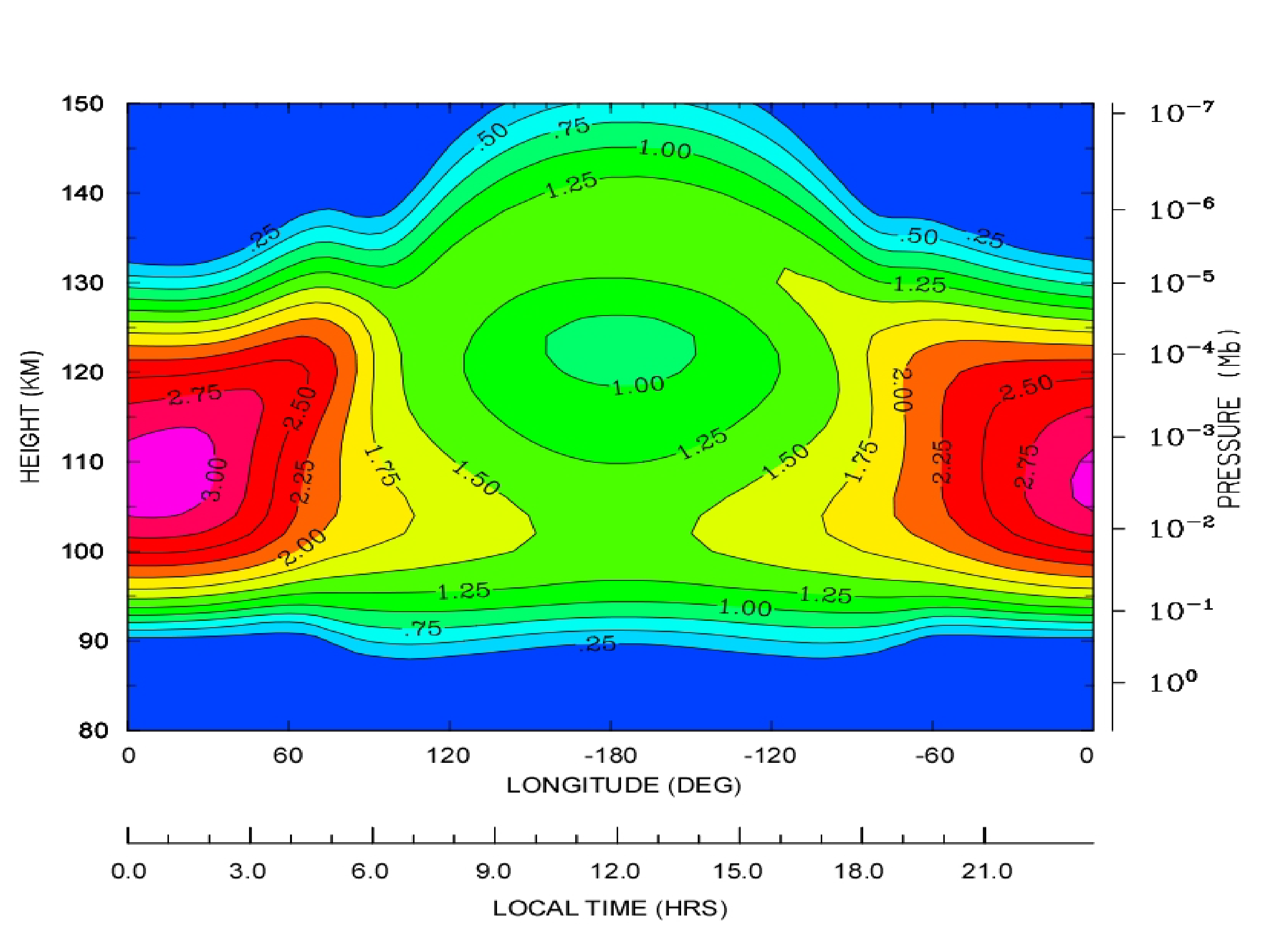
# Venus Helium Bulge at 160 km: Pioneer Venus/ONMS (Mengel et al. 1989)



# Venus Thermospheric Circulation Paradigm: Schubert et al. (2007)

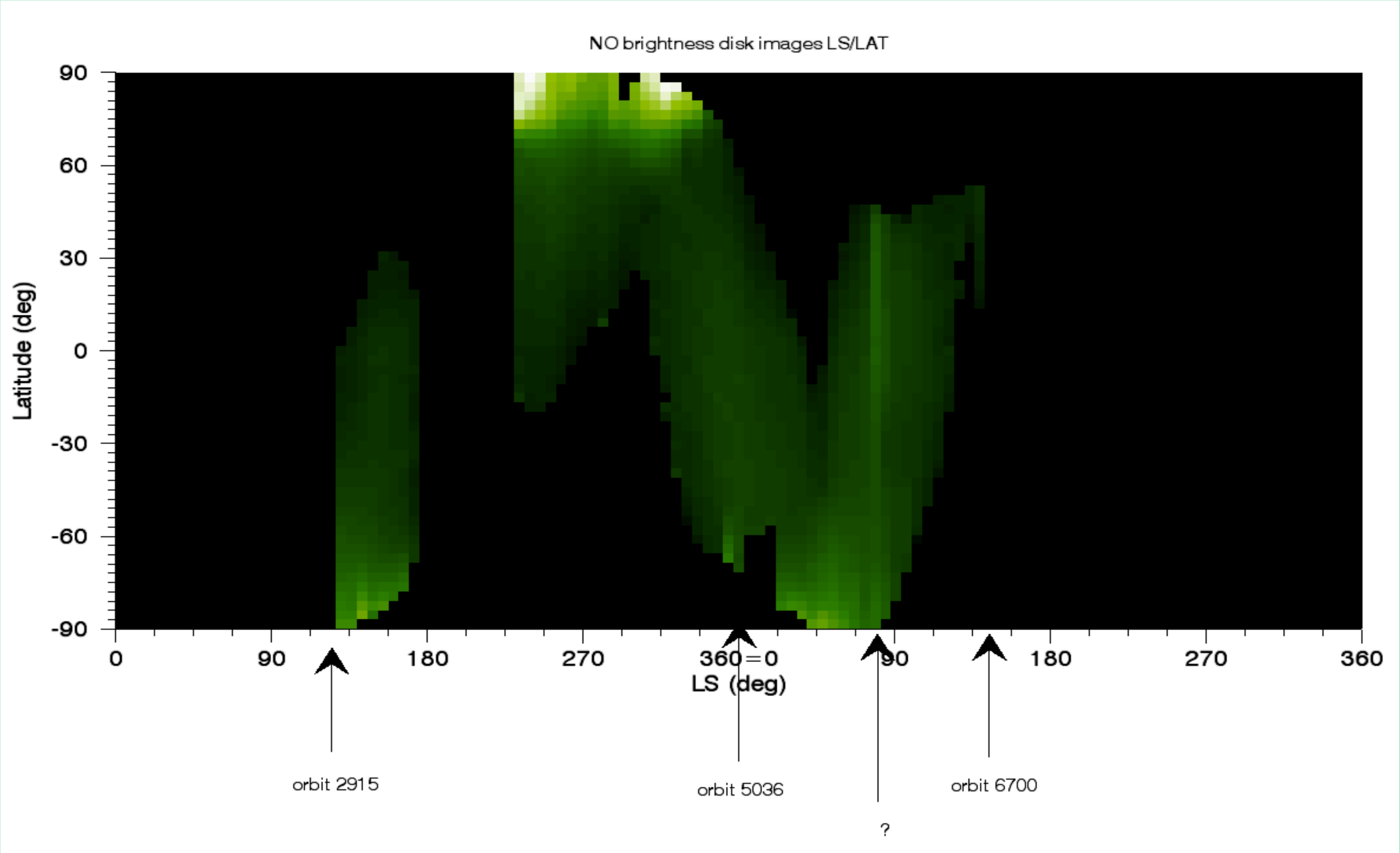


# VTGCM NO Nightglow VER Map (VEx/SMIN): Bougher et al. (2013); Gerard et al. (2018)



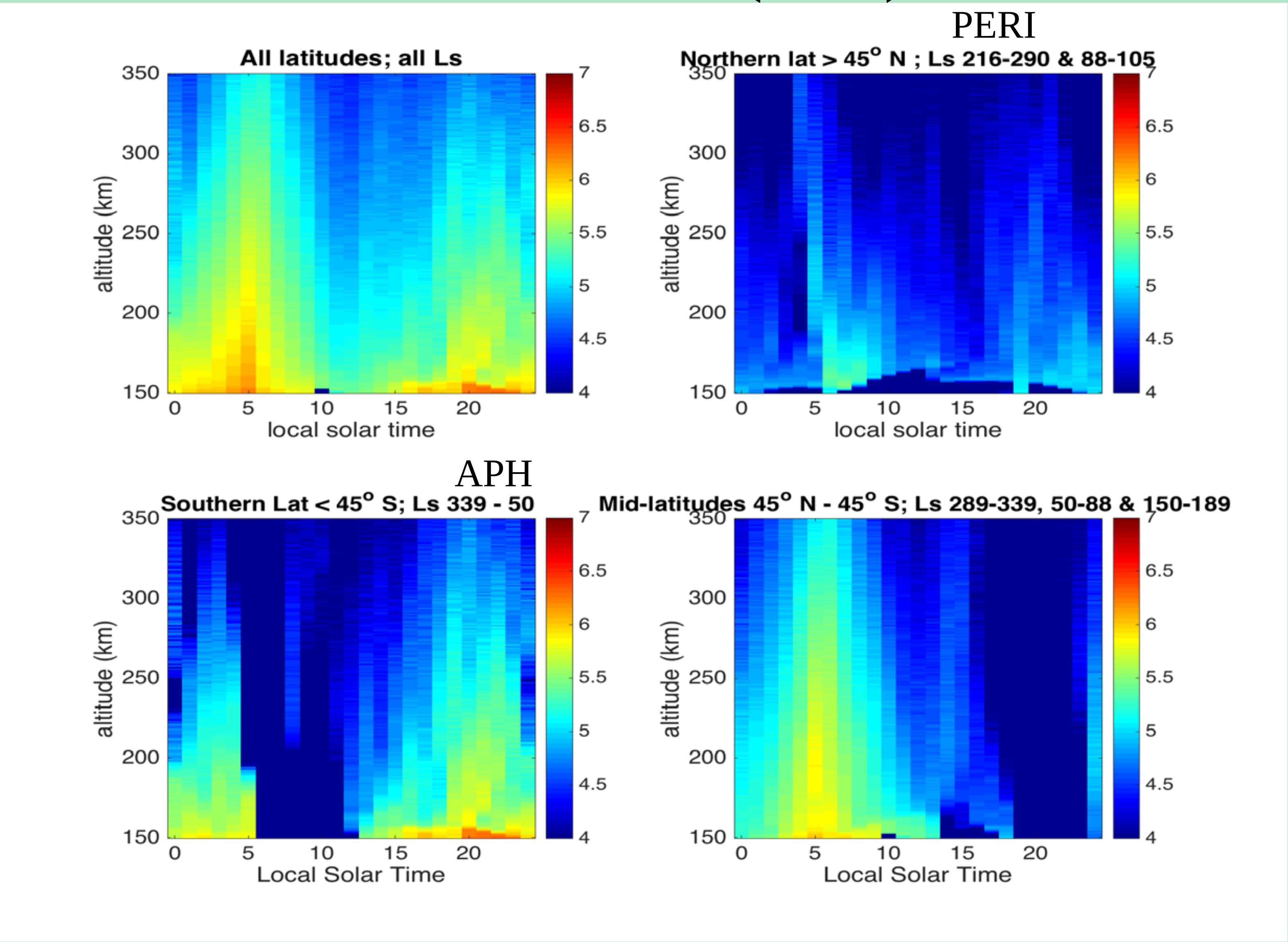

Volume Emission Rate: $\log_{10}$ (photons/$cm^3$/s)

# MAVEN/IUVS Disk Apoapse Images of Brightness of NO Nightglow: Stiepen et al. (2018)



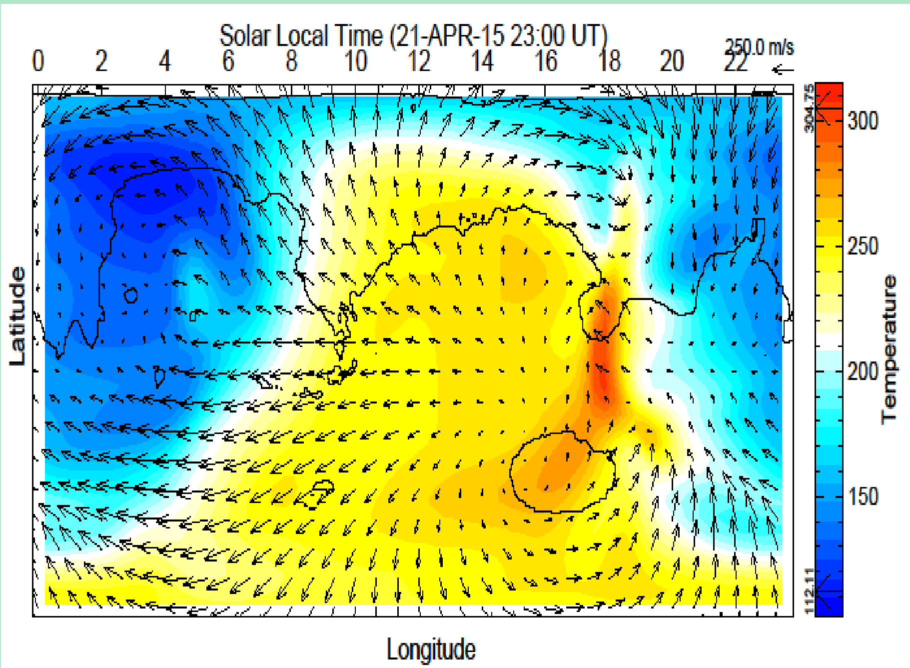

Seasonal distribution shows brightening at winter poles with strong solstice asymmetries. Data cover full MY, with gaps.

# Mars Helium Bulge : MAVEN/NGIMS
# Elrod et al. (2017)

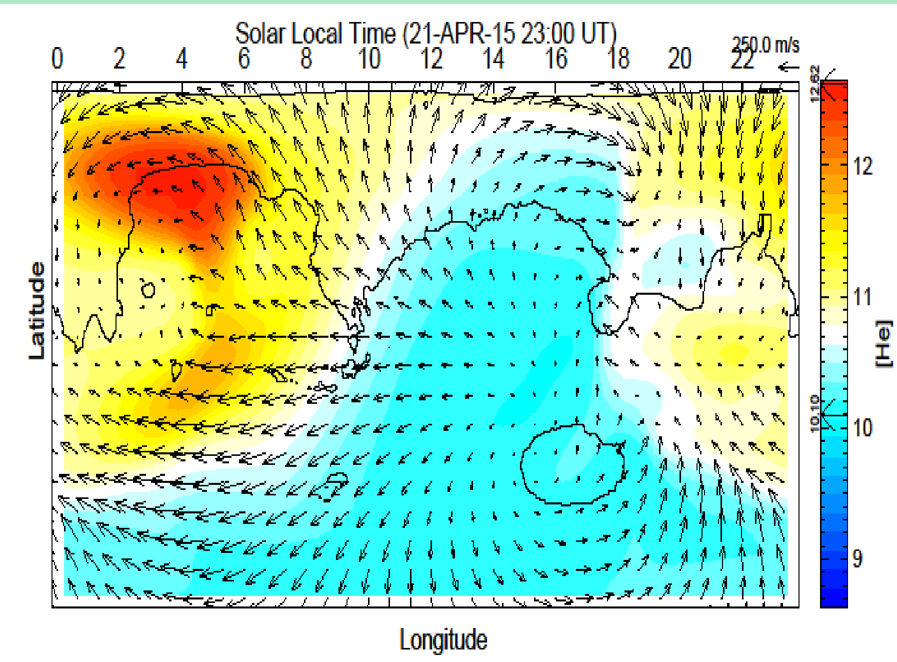


# M-GITM T+(U,V) and Helium density at ~200 km: DD2 Conditions (Ls ~ 328; SMED)

## T+(U,V)



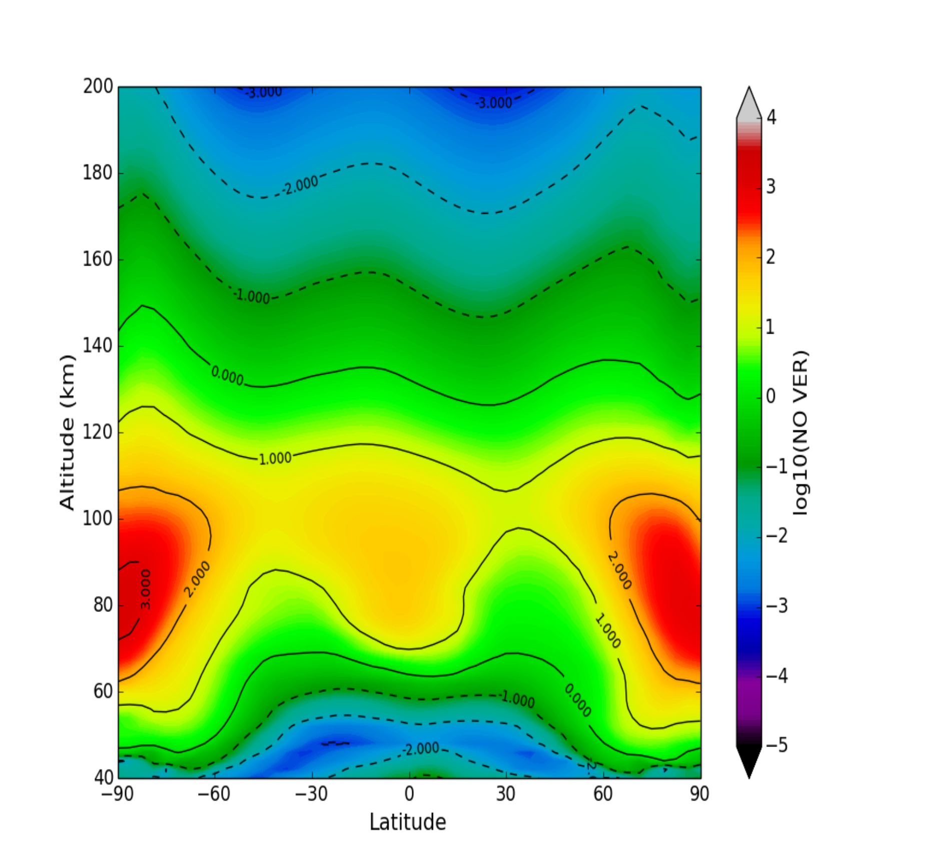

## He-Density



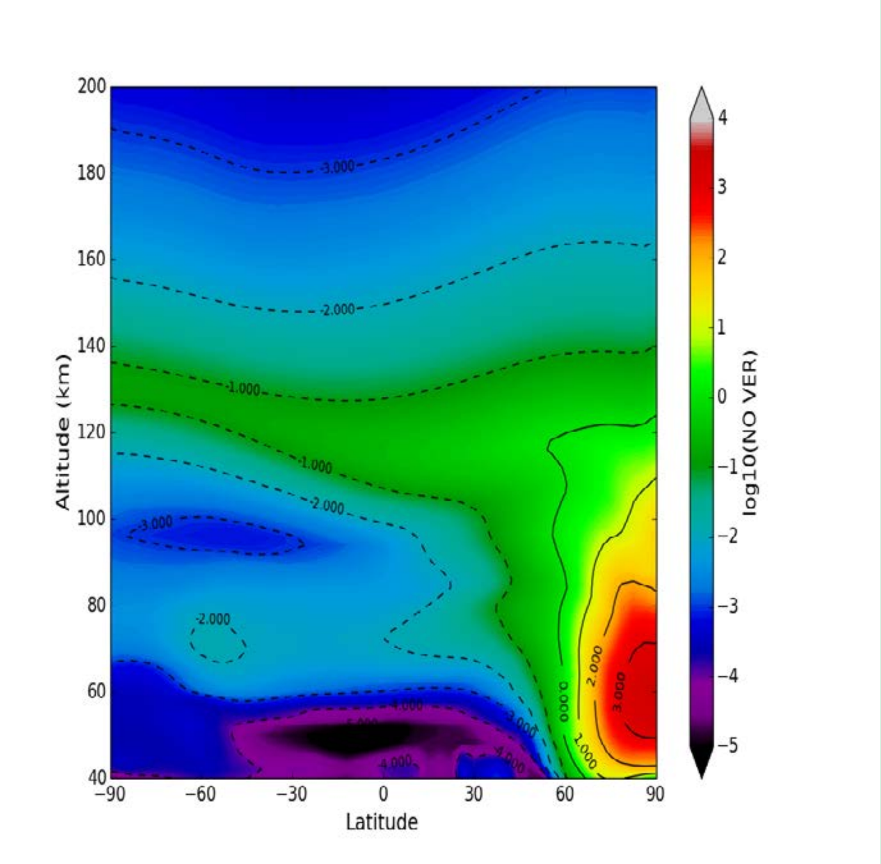

- Low SZA temperatures peak (Texo ~ 260-270 K) along with $CO_2$ densities.
- High SZA (winter polar night) temperatures are a minimum along with $CO_2$ densities.
- Divergence (upwelling, day) and convergence (downwelling, night) of the circulation
- Winter polar night (LT ~ 2-5) peak in He densities seen, corresponding to wind transport (horizontal & vertical). He shows opposite behavior of [$CO_2$] distribution.

# LMD-MGCM VER Map of NO Nightglow (Gonzalez-Galindo, 2018). In preparation

Ls ~ 0-30; LT = 4 (Equinox)




Ls = 270-300; LT = 4 (Perihelion)

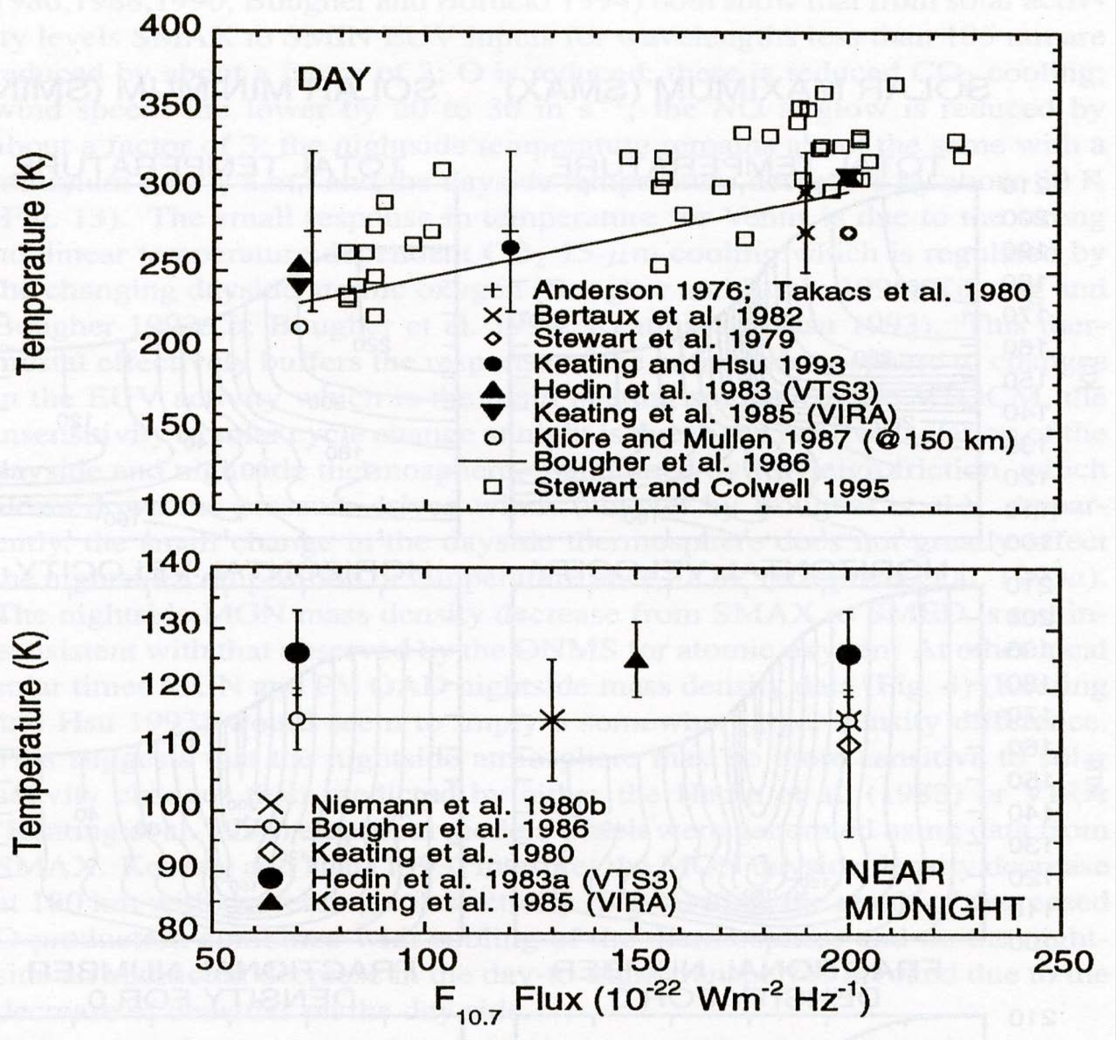



Units: $\log_{10}$ (photons/cm$^3$/s)

# Diagnostic Thermal Balances using GCMs: VTGCM, TIE-GCM, and M-GITM

| | VTGCM | TIE-GCM | M-GITM* |
|---|---|---|---|
| Altitude Range | **~70-250 km** | ~95-800 km | **~0-250 km** |
| Vert. Resolution (pressure coor.) | **H/2 or H/4** | H/2 or H/4 | **H/4 typical** |
| Horz. Resolution | **5x5 or 2.5x2.5°** | 5x5 or 2.5x2.5° | **5.0 x 5.0° thusfar** |
| Major Neutrals | **T, U, V, W, $CO_2$, CO, $N_2$,O** | T, U, V, W, O, $N_2$, $O_2$ | **T, U, V, W, $CO_2$, CO, $N_2$,O** |
| Major Ions | **$O_2$+, $CO_2$+, O+, $N_2$+, NO+** | $O_2$+,$N_2$+,O+, NO+, N+ | **$O_2$+, $CO_2$+, O+, $N_2$+, NO+** |
| Minor Neutrals | **N($^4$S), N($^2$D), NO, Ar, $O_2$** | N(4S), N(2D), NO | **N($^4$S), Ar, He, $O_2$** |
| Rad. Cooling | **$CO_2$ (15-µm)** | $CO_2$ (15-µm) NO (5.3-µm) O (63-µm) | **$CO_2$ 15-µm O (63-µm)** |

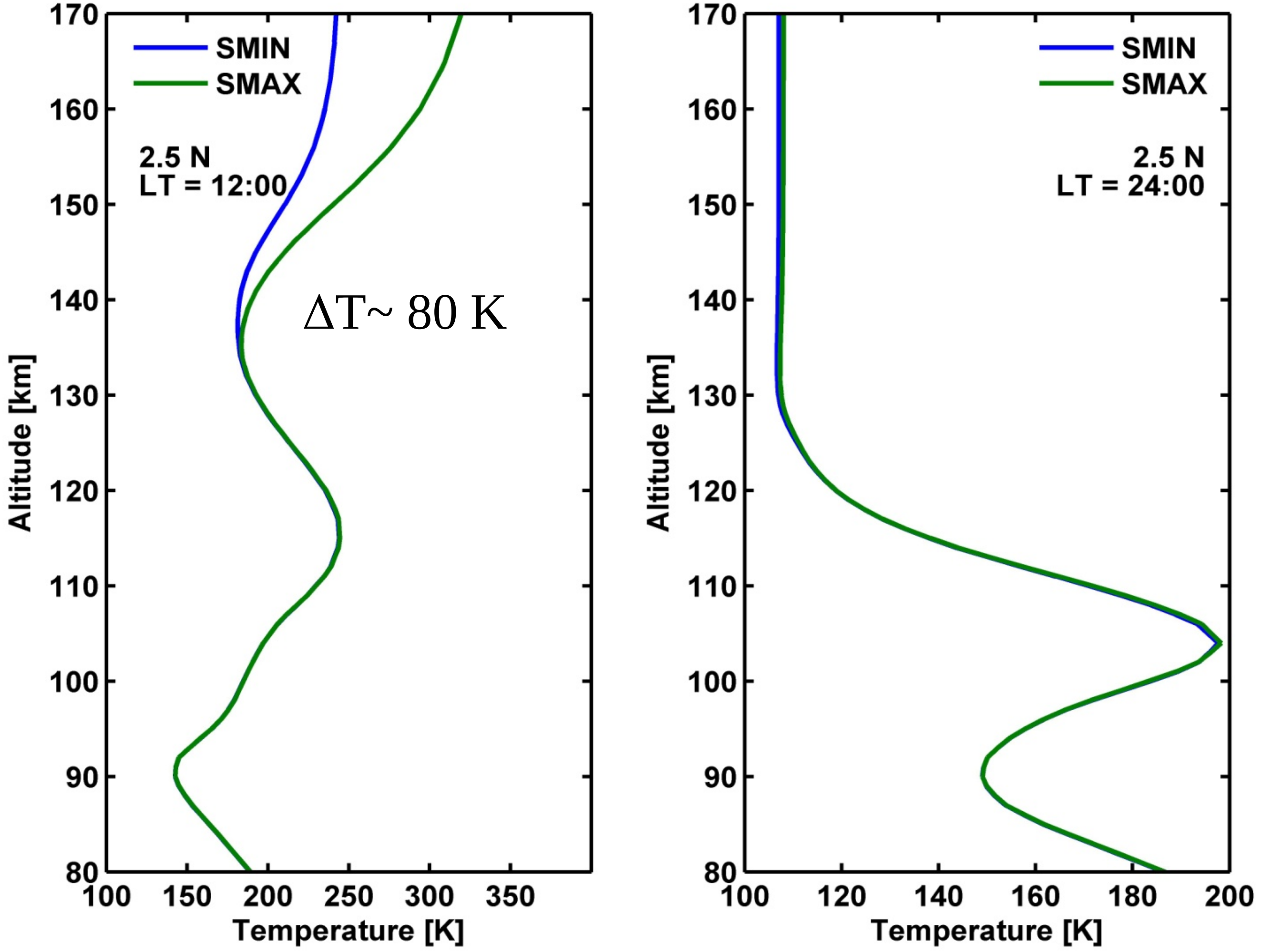
# Venus Dayside-Nightside Exospheric Temperatures: Kasprzak et al. (1997) Pioneer Venus



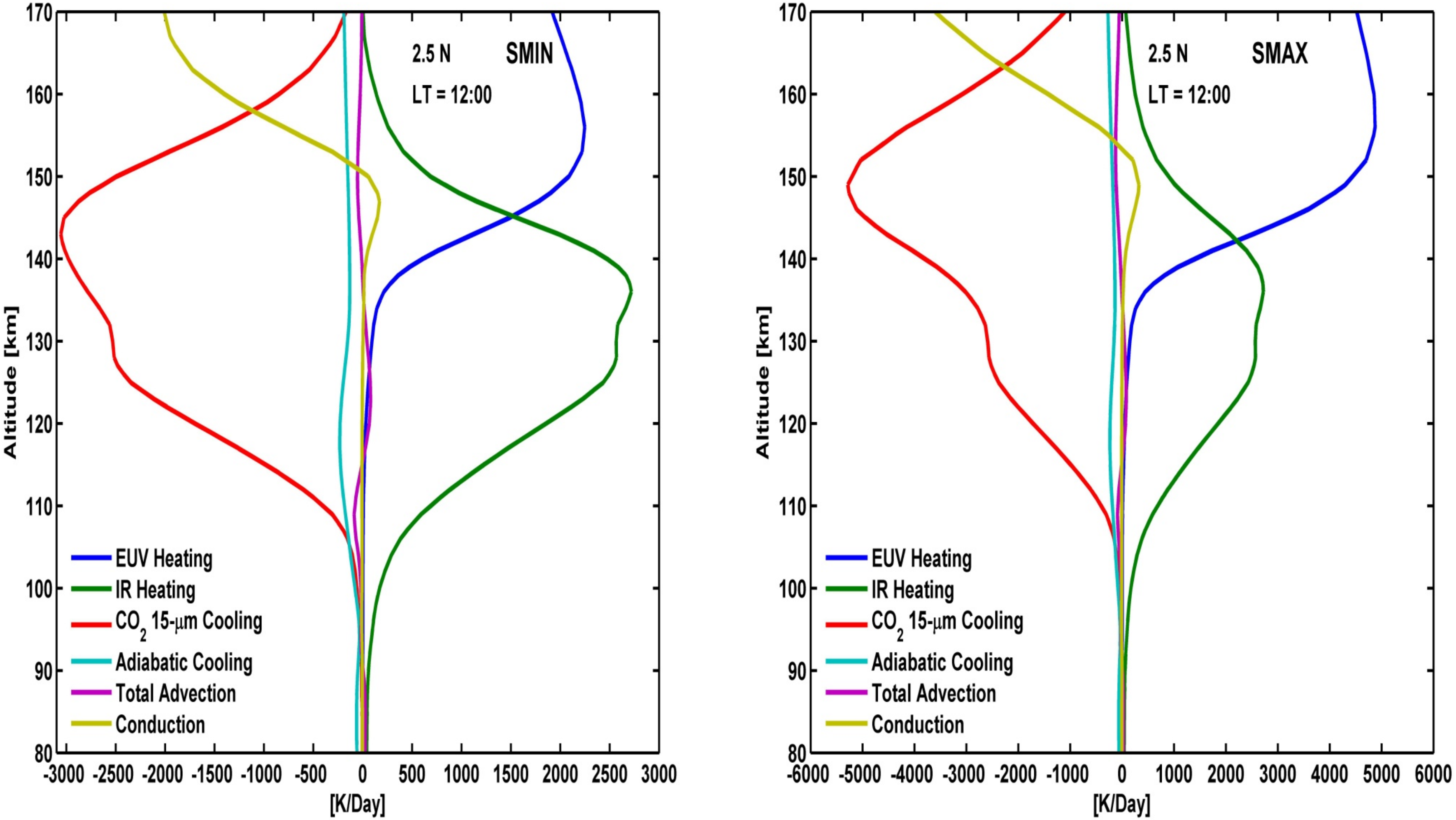

$\Delta T \sim 70\text{-}80$ K (at Venus)

Nearly Constant

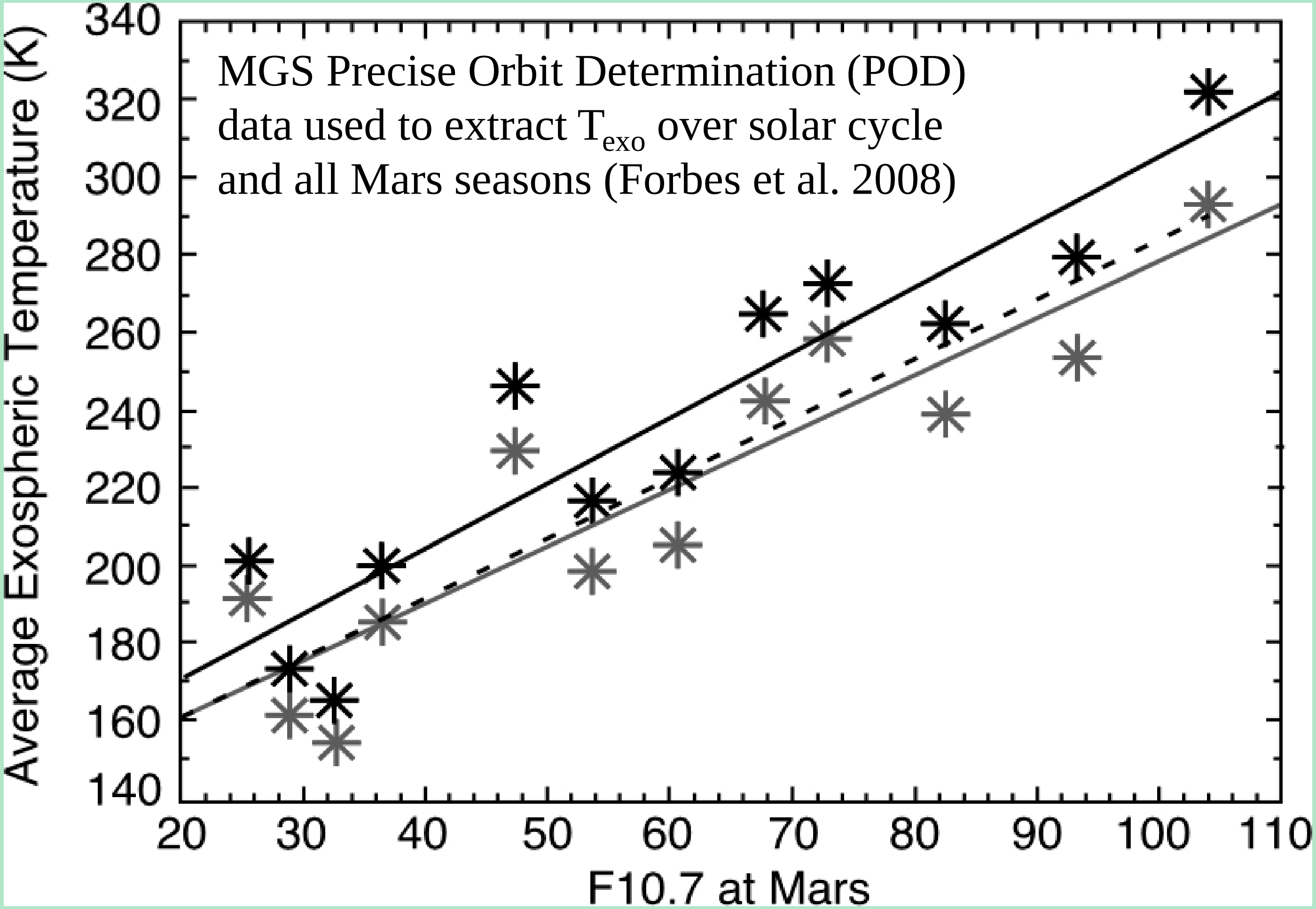
# VTGCM T-Profiles: Dayside and Nightside for SMIN and SMAX Conditions



# VTGCM Thermal Balances at SZA = 0:
# (SMIN/VEX and SMAX/PVO Conditions)

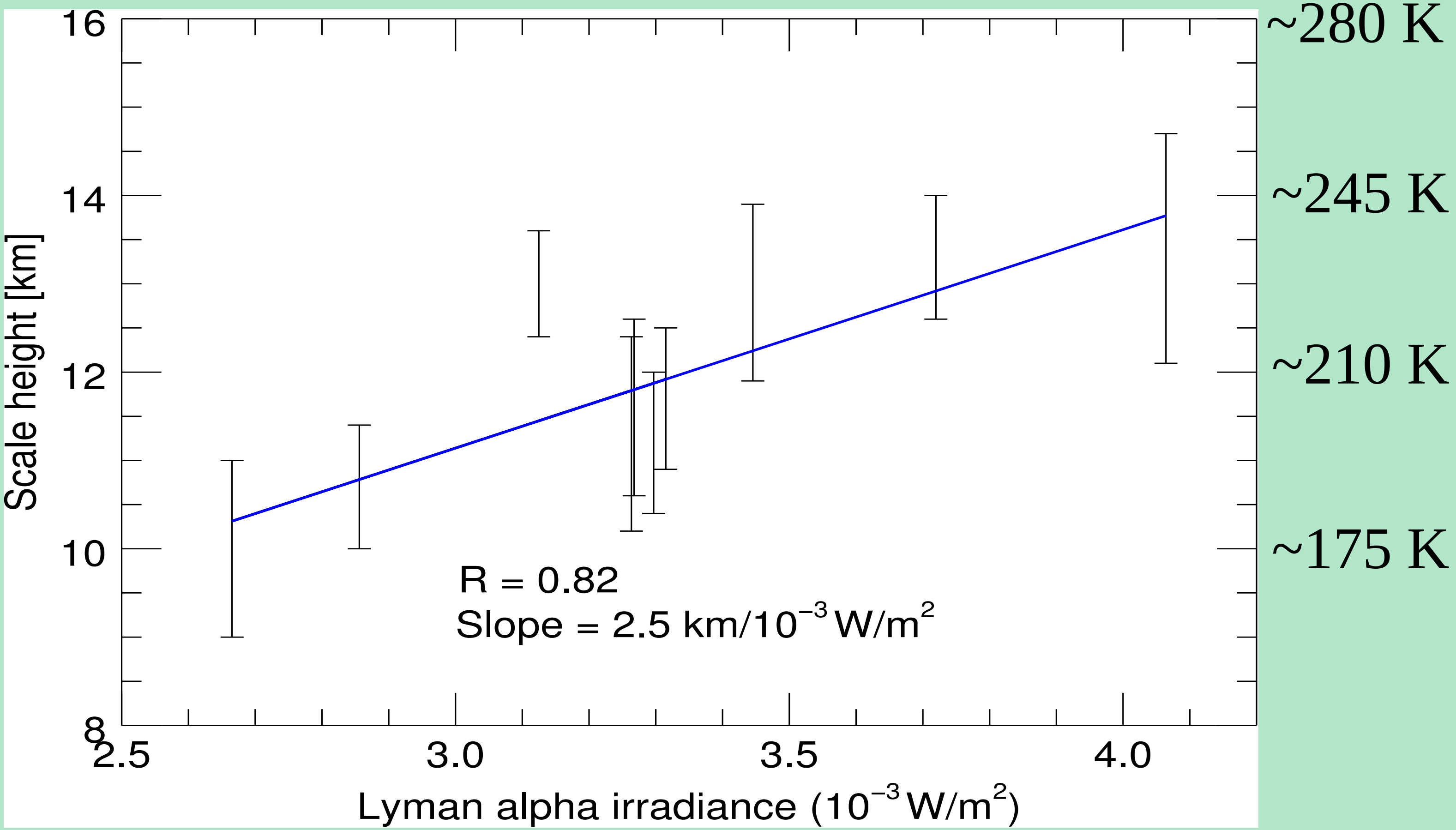


# Mars Texo Variations Over Solar Cycle: Bougher et al (2009) Pre-MAVEN



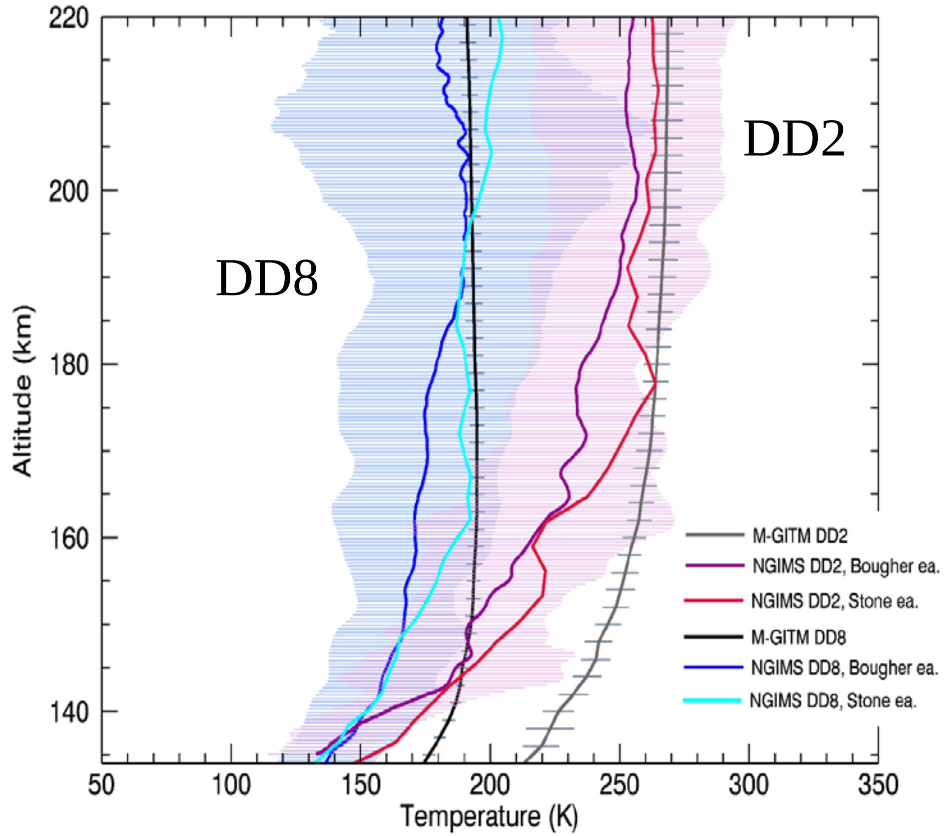

$T_{min}$ ~ 165K; $T_{max}$ ~ 315K; $T_{avg}$ ~ 240K

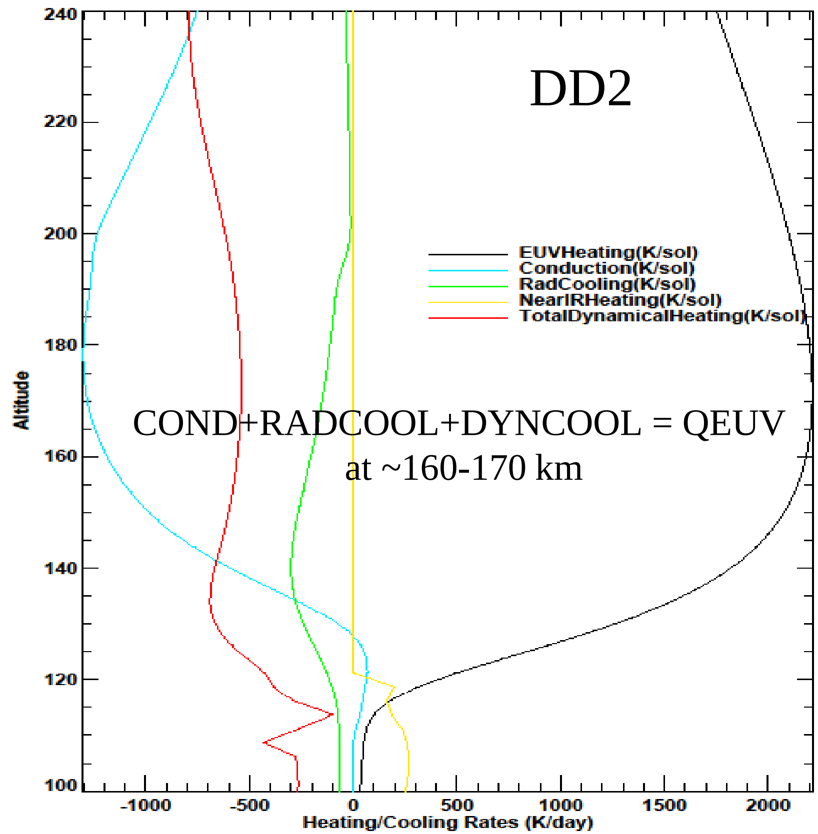
# IUVS Dayglow Scale Height (~150-180 km) vs Lyman-α Irradiance (1-MY): Jain et al. (2018)




- Temperatures (scale heights) are highly correlated with incoming solar EUV
- Scale heights are also highly correlated with Sun-Mars distance

# DD2 versus DD8 Averaged Dayside T- Profiles: NGIMS-MGITM Comparisons + Thermal Balances




Texo ~ 270 K (MGITM) and ~265 K (Stone et al. 2018): DD2

Texo ~ 190-200 K (MGITM) and ~190-200 K (Stone et al. 2018): DD8

ΔTexo ~ 65-70 K (DD2: SMED/EQU to DD8: SMIN/APH)

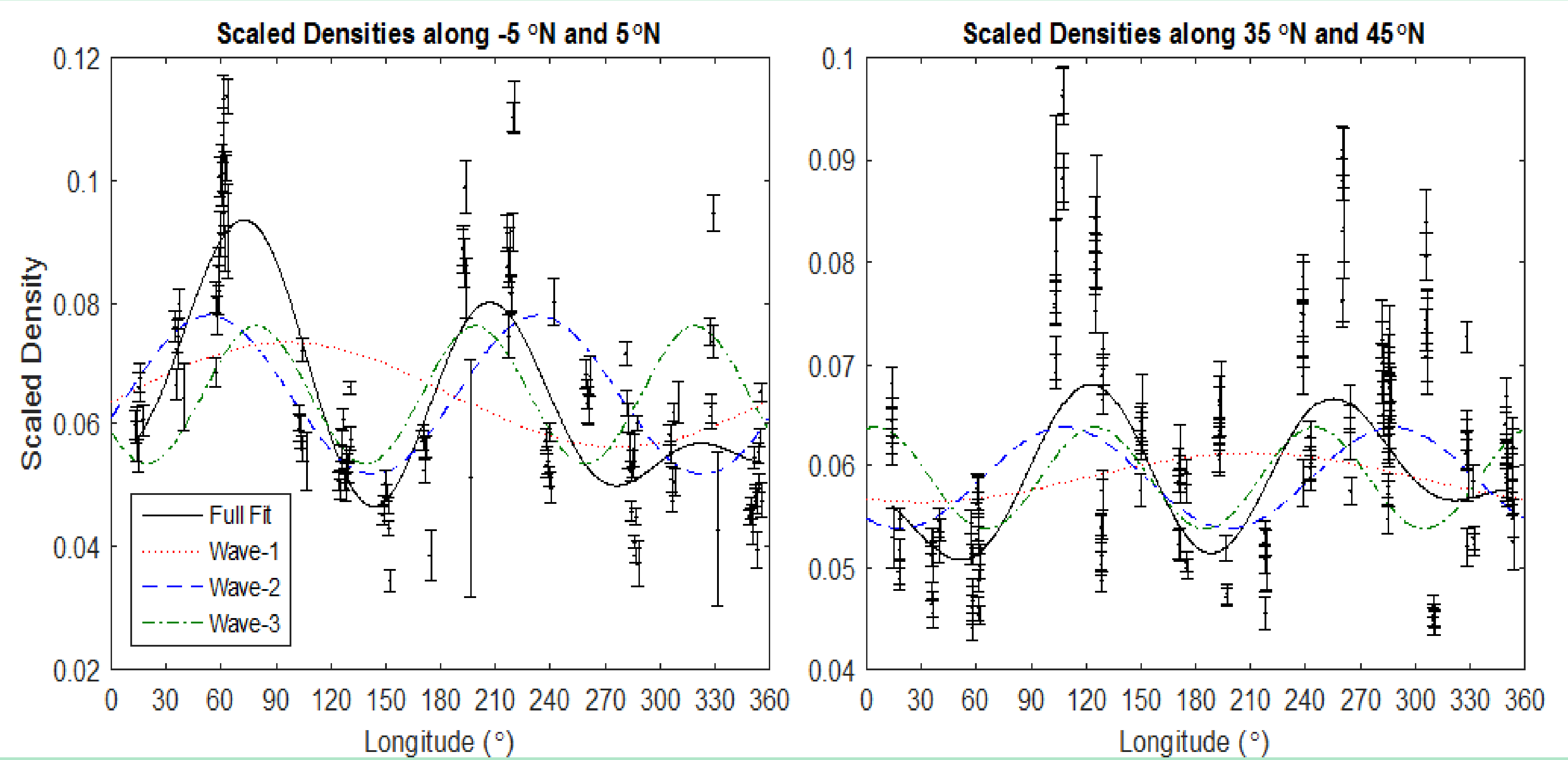
# Lower to Upper Atmosphere Coupling with Examples from Mars Spacecraft Observations

# Summary of Primary Tidal Forcings for Earth and Mars (Siskind & Bougher, 2016)

| Tidal Component | Earth | Mars |
| --- | --- | --- |
| Migrating diurnal | NIR abs. of $H_2O$ | VIS and IR abs of $CO_2$ |
| Migrating semi-diurnal | Ozone heating | Dust heating |
| Non-migrating | Latent heat release from tropical convection | Topographical and pl. wave modulation of near surface heating |

- Similar rotation rates of Earth and Mars imply that the mathematical characteristics of the tidal modes for Earth and Mars are similar.
- In general, due to large topographic variations, the manifestation of these tides in the Martian upper atmosphere is greater on Mars than Earth.
- Overall: Local time sorting is needed to go beyond harmonic analysis to address identification of specific tides.

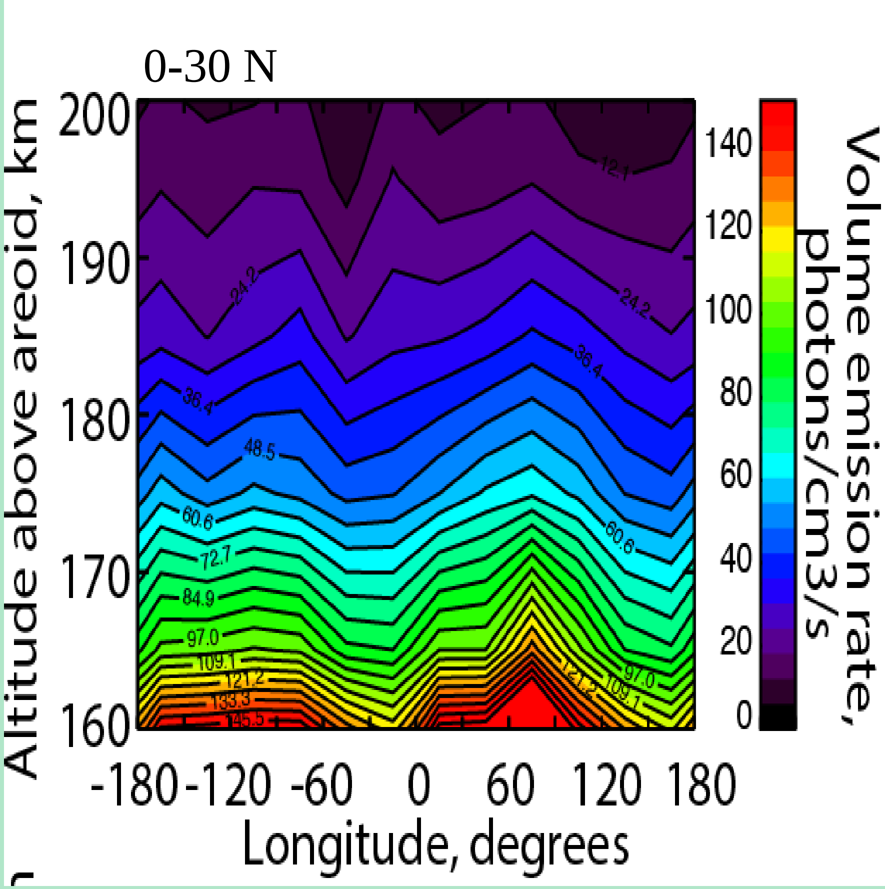
# MAVEN IUVS $CO_2^+$ UVD Derived $CO_2$ Density Variations in Longitude (Lo et al. 2015)



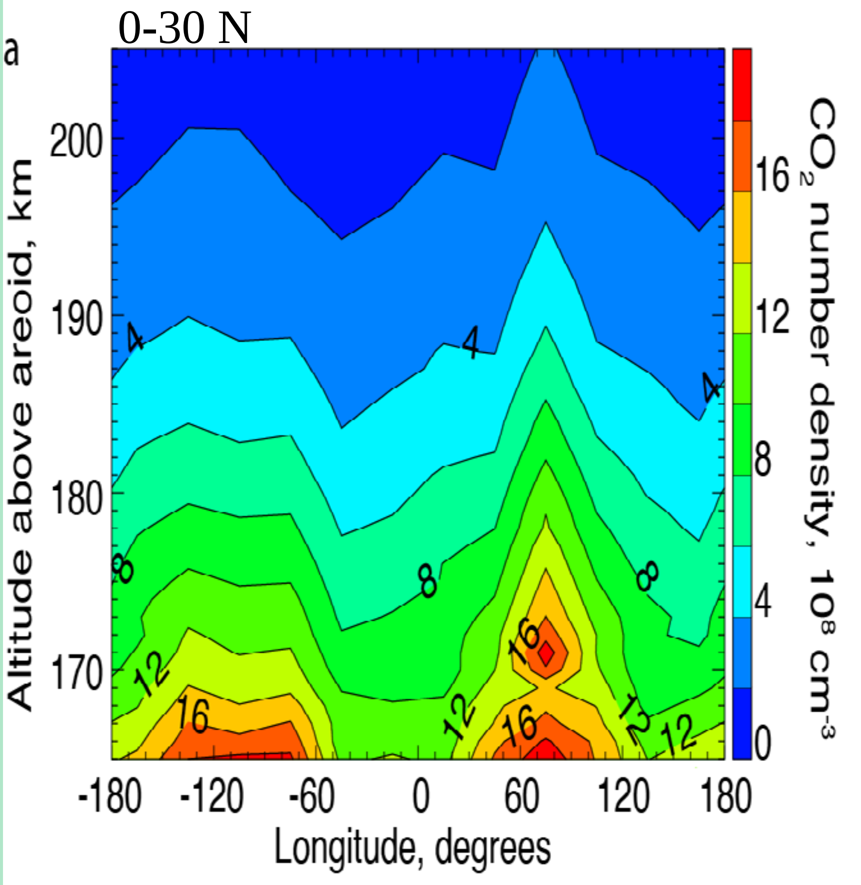

Harmonic fits to LON variations in $CO_2$ densities as observed by IUVS at 130 km. Wave-2 has largest amplitude (~20-30%) and near constant phase at low LAT.

# IUVS $CO_2^+$ VER and NGIMS $CO_2$ Variations in Longitude (England et al. 2016)

IUVS



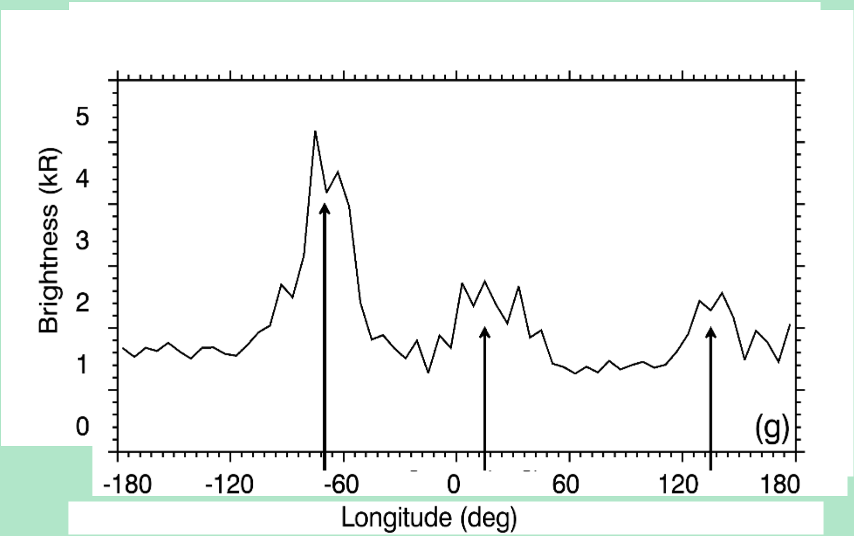

NGIMS



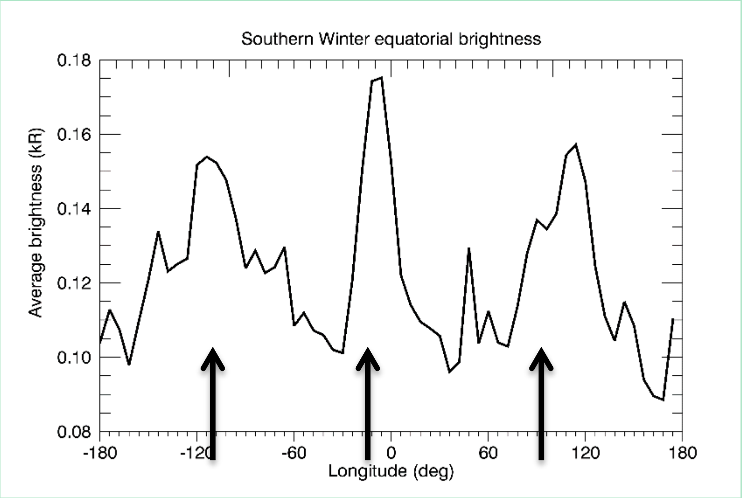

Harmonic analysis reveals wave-2 is dominant at all LATs and ALTs.
Fixed local time observations.

# IUVS NO Nightglow Periapse Data & Disk Images Show Wave-3 Equatorial Structure during Southern Winter (Royer et al. (2017))

Periapse data: 80 < Ls < 120




Disk images: 130 < Ls < 170

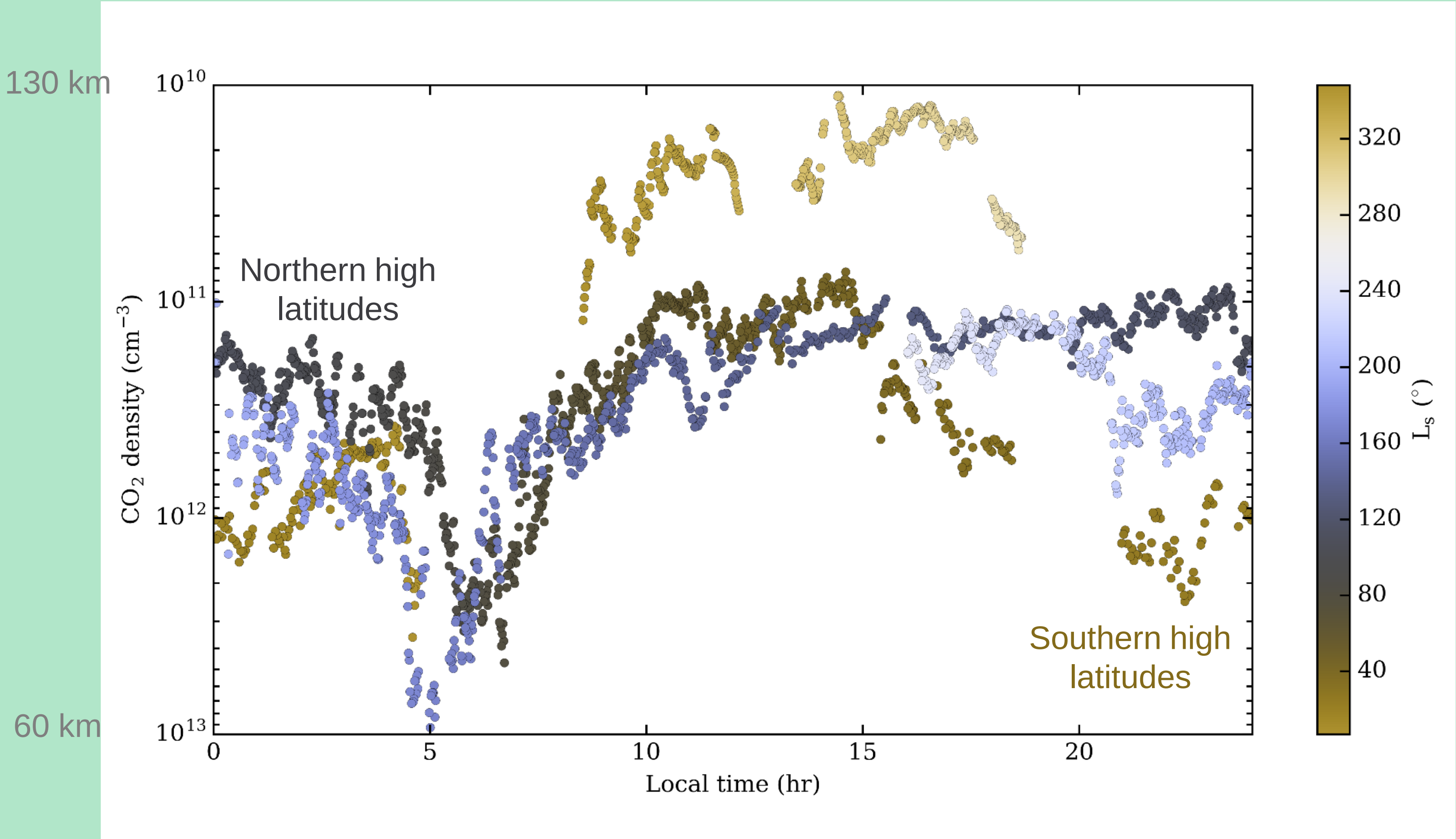



~1 Martian Year apart
Same equatorial latitude range

We observe:

- Changes in the longitudes of the peaks,
- Changes in the space between each peak,
- Changes in the ratio between enhanced regions

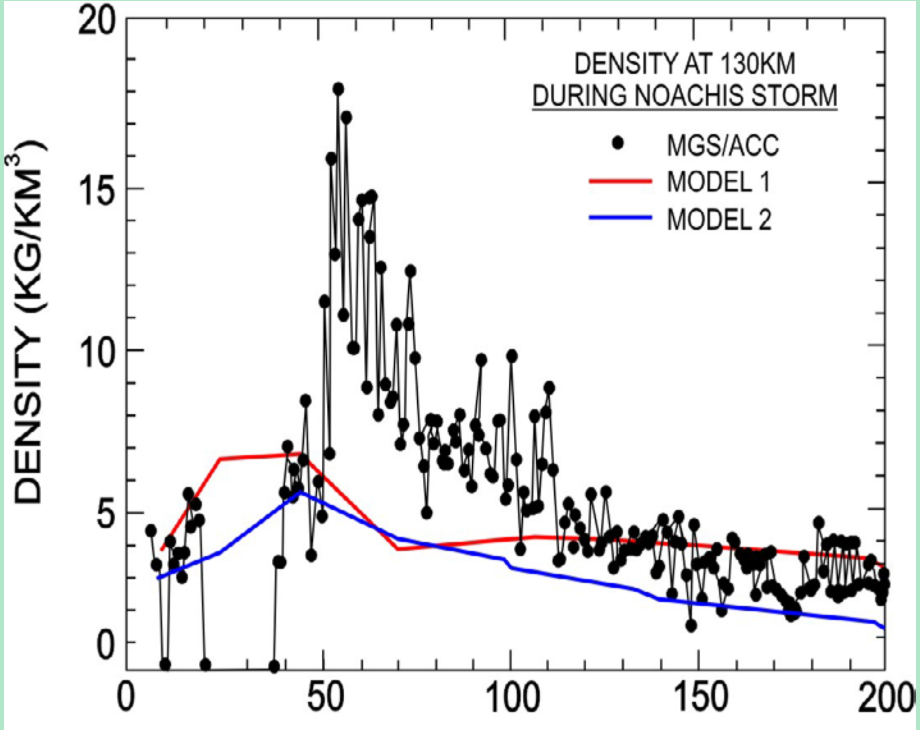
# Mars Homopause Altitudes Derived from NGIMS $N_2$/Ar Ratios: Slipski et al. (2017)




- Homopause varies significantly and does not track a fixed density level
- Lowest homopause altitudes occur between 4 – 6 AM and the highest values near noon when Ls > 270° (near perihelion). Implies Kzz ~ 10 to 10,000 $m^2$/s

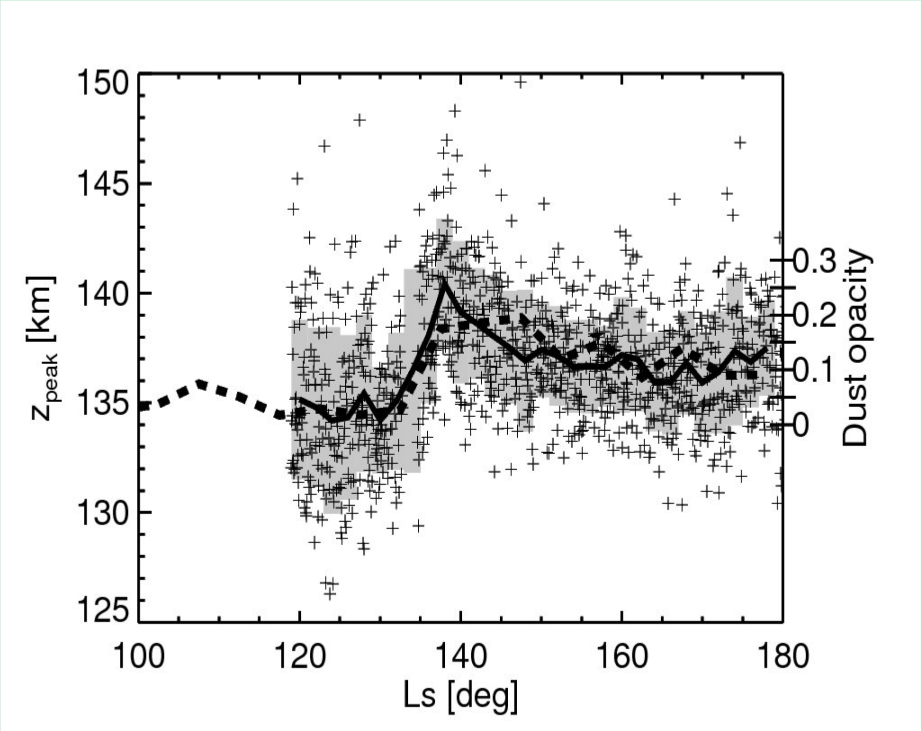
# Dust Storm Impacts on Mars Thermosphere: Regional Storms

**MY23 Noachis Storm (Ls ~ 224): Mass Density at 130 km (Bougher et al., 1999)**




**MGS Orbit Number**

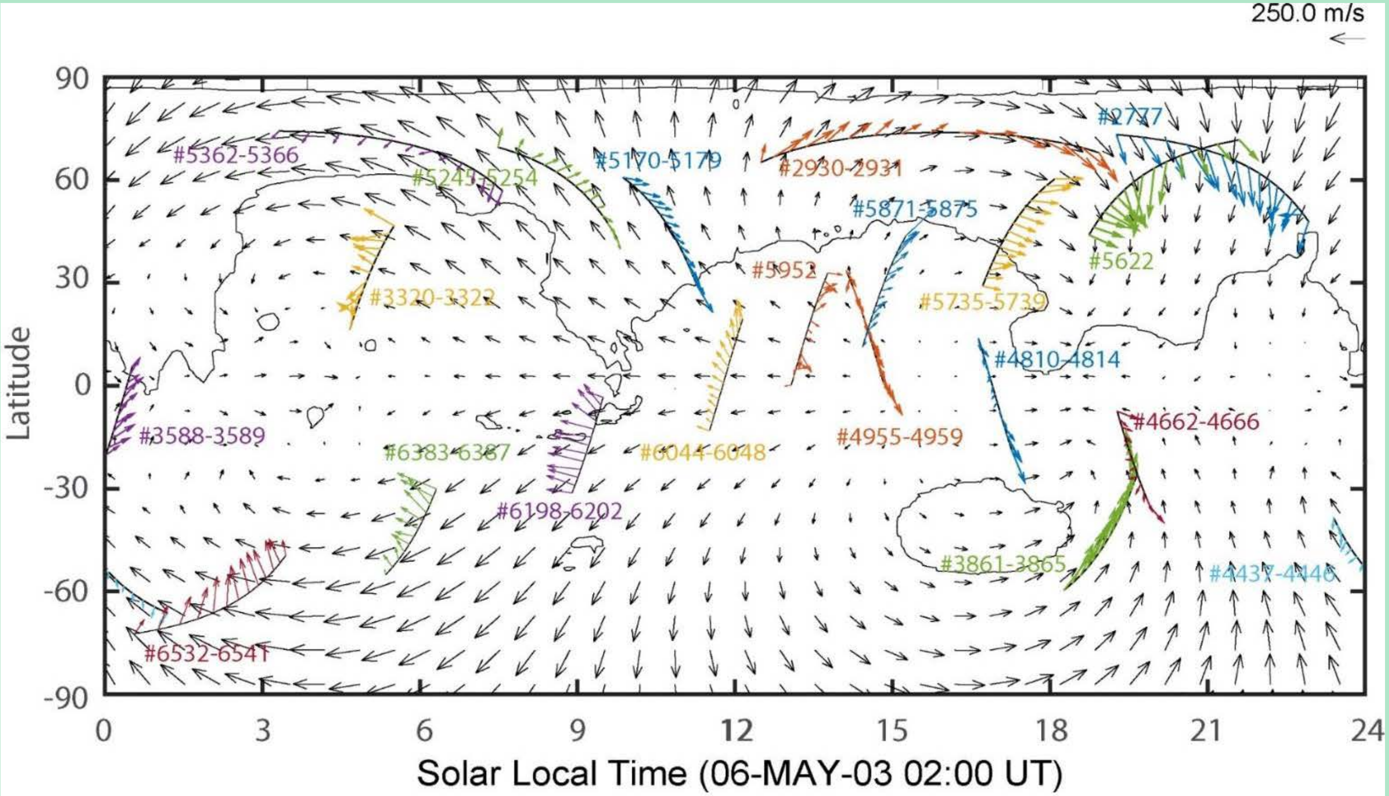
**MY27 Storm (Ls ~ 130): Ion Peak Height (Withers & Pratt, 2013)**




**MGS Radio Occultations**

**NGIMS sampling during regional storms (Jan-Apr 2017) and impacts over 170-220 km (Liu et al., 2018). ~50-200% density enhancements.

# Thermospheric Neutral Winds Derived From NGIMS Observations (Roeten et al., 2018)




- Winds were derived below ~200 km using technique of “yawing” NGIMS left/right; monthly 2-day (10-orbit) campaigns since September 2016
- Large, unexpected orbit-to-orbit measured wind variability, as large as ± 100 m/s
- Comparisons with M-GITM model predictions show good agreement much of the time. However, significant differences suggest the importance of processes such as vertically propagating gravity waves and tides. Cite examples above.

# Major Take Aways

- **Planetary fundamental parameters** indeed play a significant role in determining UATM structure and dynamics on these terrestrial planets. Exoplanet (HZ) simulations possible using these planets as prototypes.

- **Solar cycle variation of dayside Texo** smallest (~70-80K) for Venus, owing to thermostatic control by $CO_2$ cooling. Mars day Texo are instead regulated by large scale dynamics, $CO_2$ cooling and thermal conduction, yielding larger variations (~70-140K) over the solar cycle.

- **Coupling of 3-terrestrial planet thermospheres** (from below) is very important for determining structure and dynamics (e.g. tides & dust).

- **NO nightglow** is being used effectively at Venus and Mars to serve as a tracer of UATM circulation and a monitor of short term variability. NGIMS wind measurements suggest coupling from below is likely.

- **Mars homopause altitudes** show large variations with season, latitude and local time. Consistent with large $K_{zz}$ (up to $10^8$ $cm^2/s$). 100x Earth.