Carbon Monoxide Concentrations in the Venus Troposphere from Venus Express/VIRTIS between 2006 and 2009

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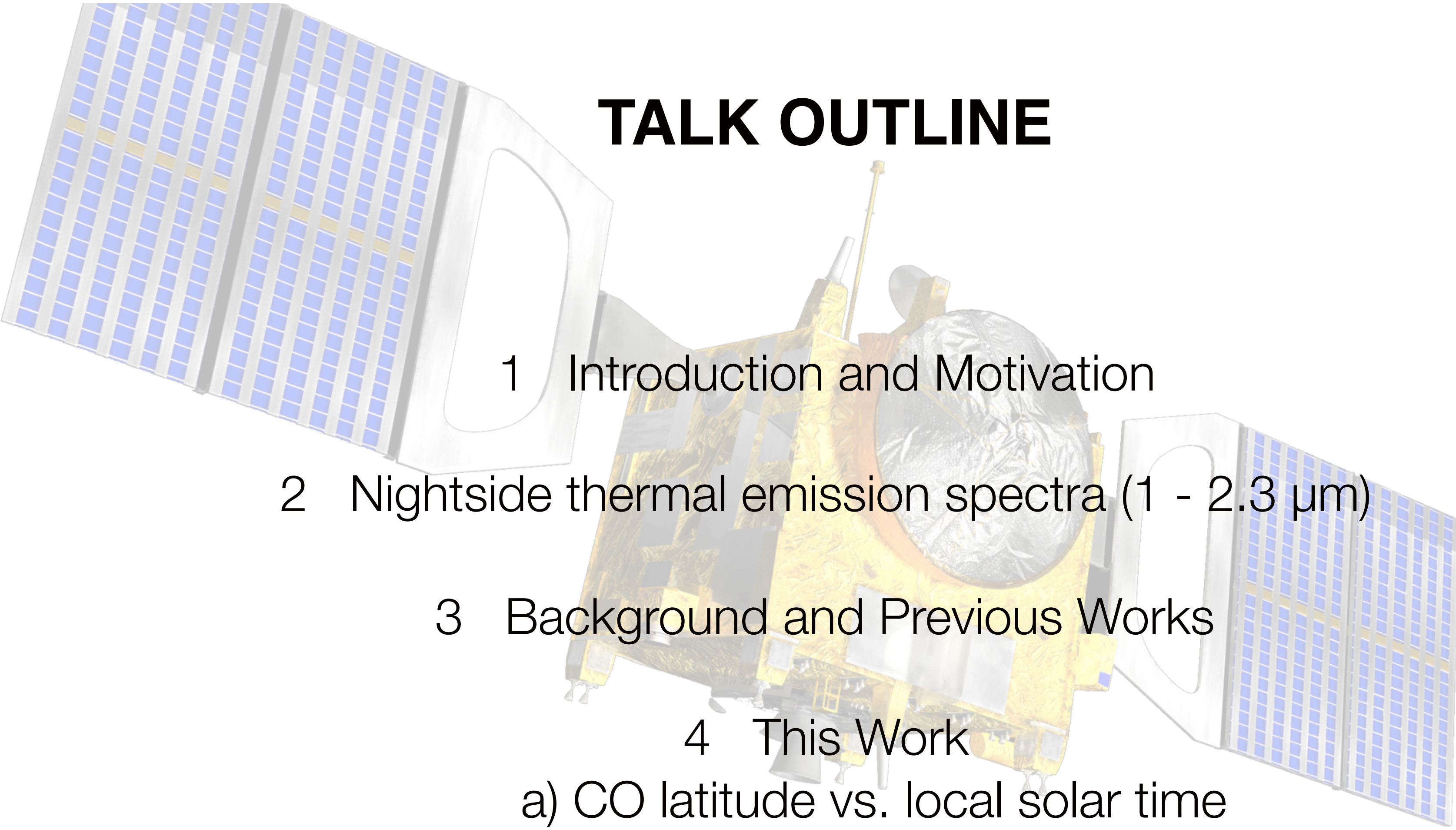
TALK OUTLINE



1 Introduction and Motivation

2 Nightside thermal emission spectra (1 - 2.3 μm)

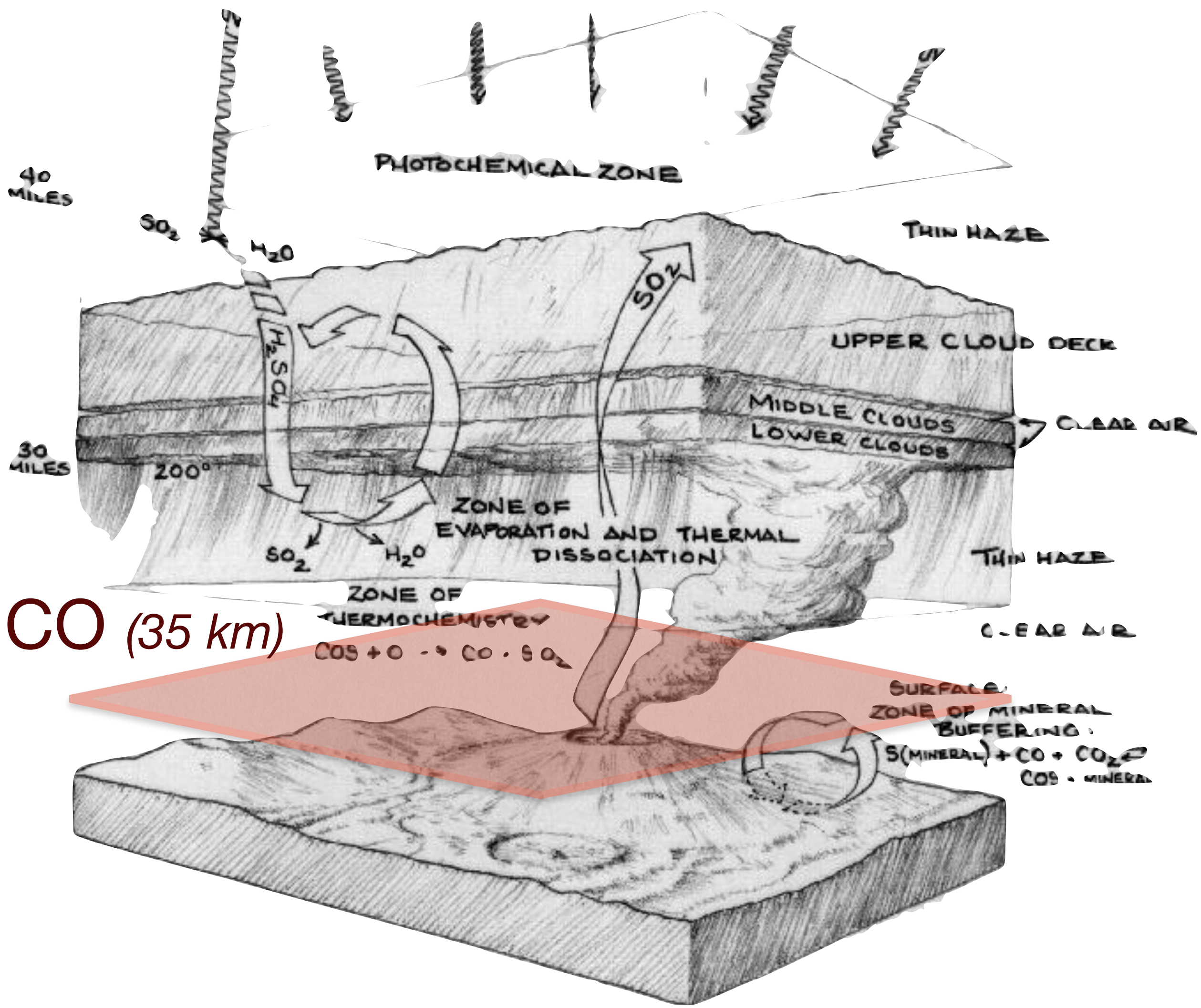
3 Background and Previous Works

4 This Work
a) CO latitude vs. local solar time
b) CO latitude vs. longitude
c) CO latitude vs. orbit-to-orbit

5 Conclusions & Future Work

INTRODUCTION & MOTIVATION

why the troposphere matters



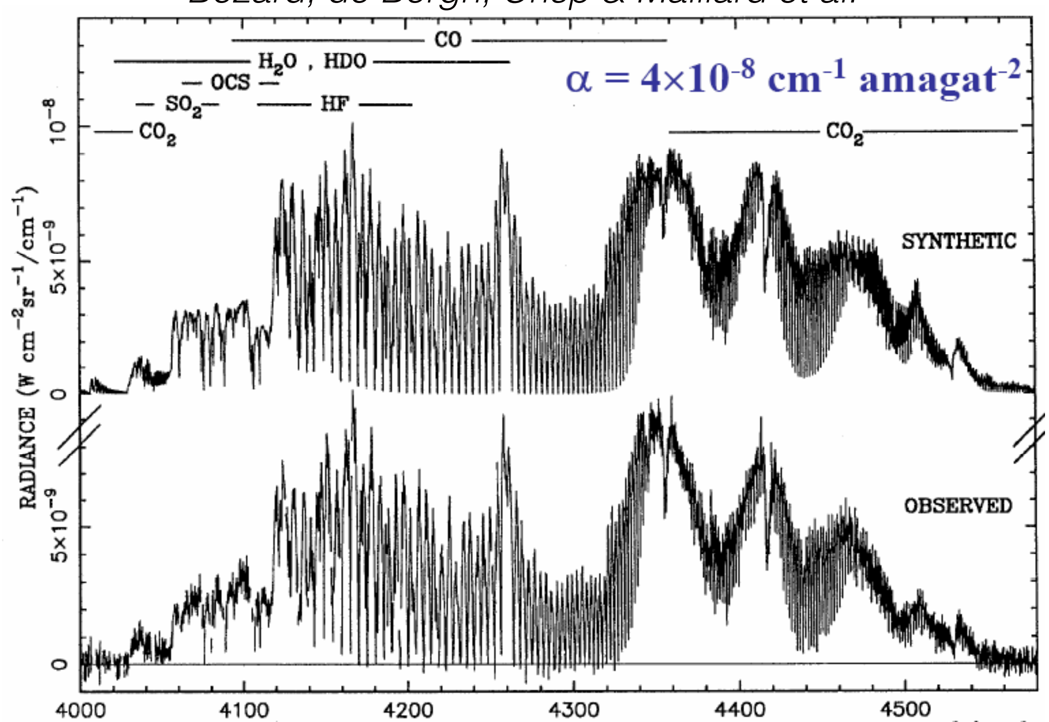
Credit: Carter Emmart in David Grinspoon's "Venus Revealed"

- The bulk of the atmosphere is in the troposphere (0-40km. Descent probes gives us insights to this region, until the discovery of nightside NIR thermal emission.
- Venus Express is the first spacecraft to remotely sound this part of the atmosphere.
- We want to understand the dynamics and chemistry, using CO as a tracer for the deepest parts of the Venus atmosphere

NIGHTSIDE THERMAL EMISSION WINDOWS

nightside thermal emission spectra and weighting functions

CFHT/FTS observations (R=0.15cm^{-1})
Bezard, de Bergh, Crisp & Maillard et al.

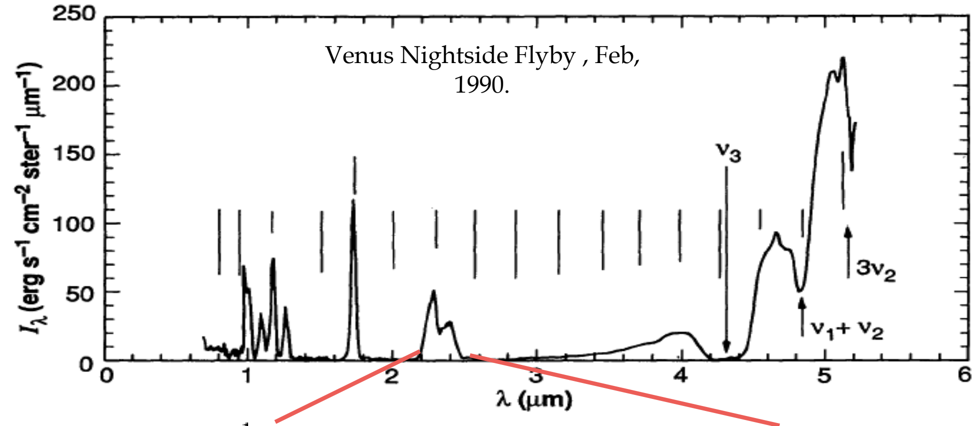


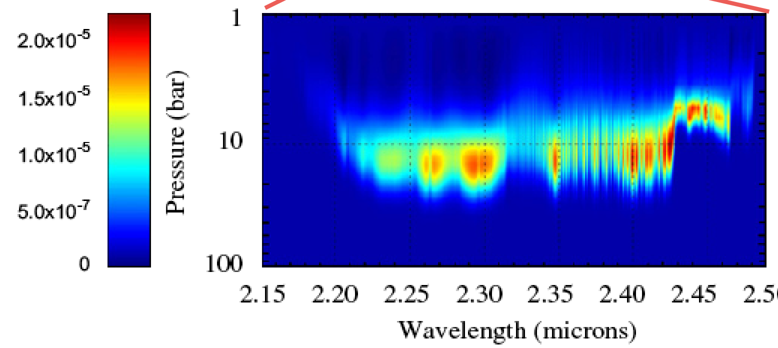
Wavenumbers (cm^{-1})

2.50 2.44 2.38 2.32 2.27 2.22

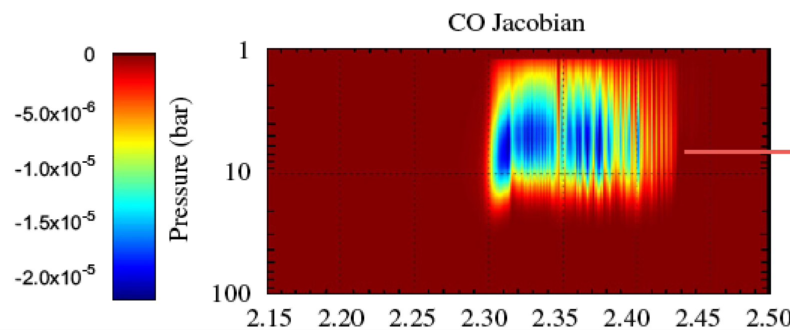
Wavelengths (lambda)

Carlson et al., 1993, PSS





Temperature Jacobian

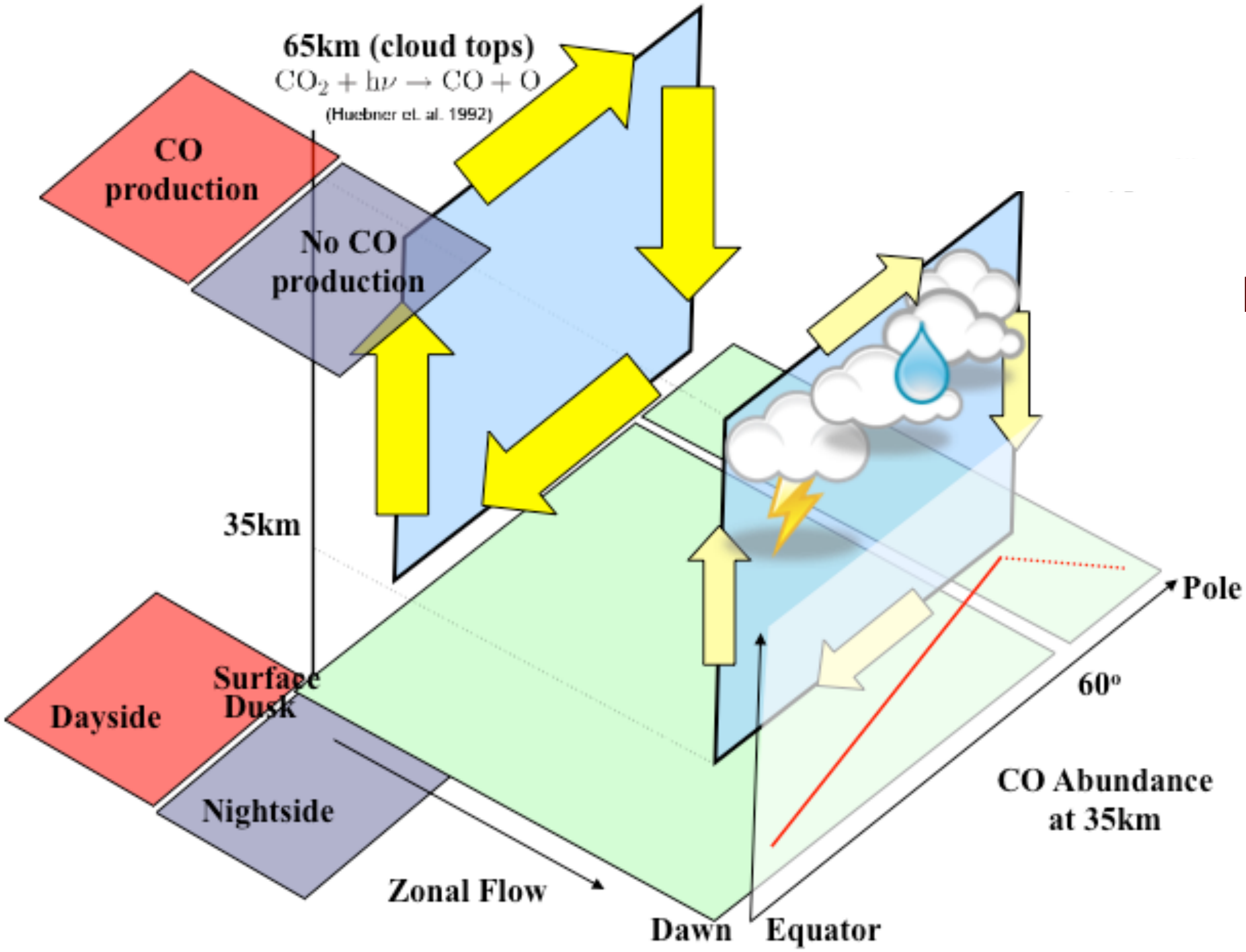


35 km

Tsang et al., 2008, JSQRT Wavelengths (microns)

PREVAILING UNDERSTANDING

CO entrainment into the deep atmosphere



Idea: Taylor 1995 ASR, Taylor & Grinspoon 2009 JGR
Figure from: Tsang et al., 2008, JGR

Mesosphere (cloud tops)

$2\ CO_2 + OCS\ (+\ UV) = 3\ CO + SO_2$

Krasnopolsky and Pollack 1994

Net transport of CO polewards due to upper arm of Hadley-type cell

Descends in altitude at the pole(s)

Deep Troposphere (cloud base)

Descending CO flows towards equator due to return arm of meridional cell

$CO + S + CO_2 = OCS + CO_2$

Krasnopolsky and Pollack 1994
Yung et al. 2009

PREVIOUS WORK

What we know so far from observations

Body of Literature

CO at the 2.35 µm 2-0 NIR band in the troposphere (35 - 40 km)

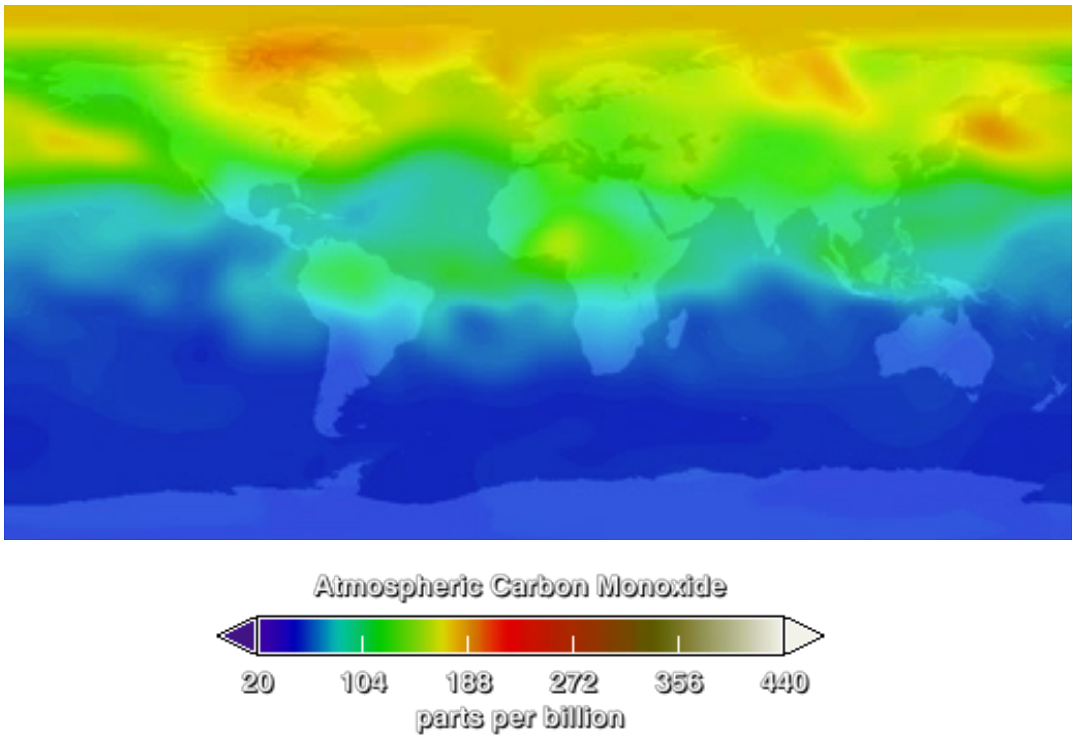
Author	DATASET	TYPE	RESULT
Bezard et al., 1990	CFHT	G	High Res spectra
Collard et al. 1993	Galileo-NIMS	S/C	CO Eq-Pole gradient
Pollack et al. 1993	CFHT	G	Significant RT agreement
Marcq et al. 2006	IRTF-SpeX	G	CO-OCS anti-correlation
Marcq et al. 2008	VEx-VIRTIS-H	S/C	High-res. spec
Tsang et al. 2008	VEx-VIRTIS-M	S/C	Full 2-D Retrievals
Tsang et al. 2009	VEx-VIRTIS-M	S/C	Band ratio method CO
Cotton et al. 2012	AAT-IRIS2	G	Sensitivity to 40 km
Barstow et al. 2012	VEx-VIRTIS-M	S/C	Band ratio method COD, acidity, CO, H_2O
Arney et al. 2014	APO-TripleSpec	G	CO N-S dichotomy switch*

Disclaimer: *If I missed your favorite CO paper, and/or paraphrasing your works, I apologize.*

Pet theory: *A N-S phase-shifted CO rich tropospheric bulge would also give this result. Patient pending*

THIS WORK
GOAL

Global Atmospheric Terrestrial CO in 2000



MOPITT instrument on Terra satellite at 5 km MSL

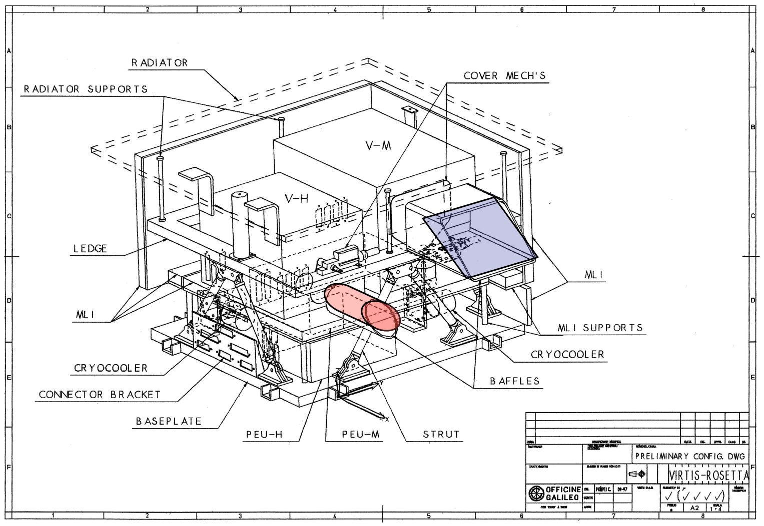
Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio

1) Global view: CO asymmetry towards the continents = shows source of CO (burning)
2) Short term, stochastic variations (magnitude and location)
3) Active tracer for the flow

VENUS: To obtain a global, time-averaged view of CO at ~35 km on Venus, to investigate underlaying local time, latitude-longitude variability, leading to insights of deep atmospheric circulation and chemistry

To provide constrains to GCM, chemistry models removing stochastic variability (hr to hr).

This Work: Venus Express/VIRTIS-M-IR



Instrument: VIRTIS-M-IR (1 - 5 μm) imaging spectrometer, Resolution~17nm, 64x64 mrad², 256x256 pixel array

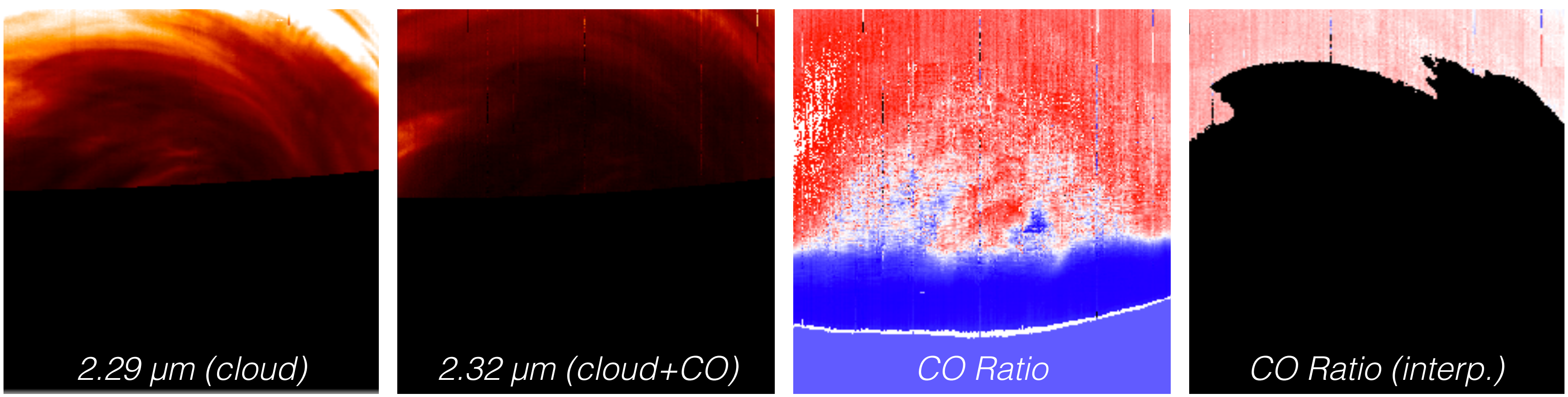
Data: April 2006 through December 2009, although most of the data in the first 1.5 years.

- ~2500 spectral image cubes, >0.03s integration

Data Procedure: correct for limb darkening, (below), interpolate to consistent 2.290 and 2.320 μm fluxes

Data Binning: Binned to 1°x1° latitude, longitude, and 1 hr local solar time (15° ZSA)

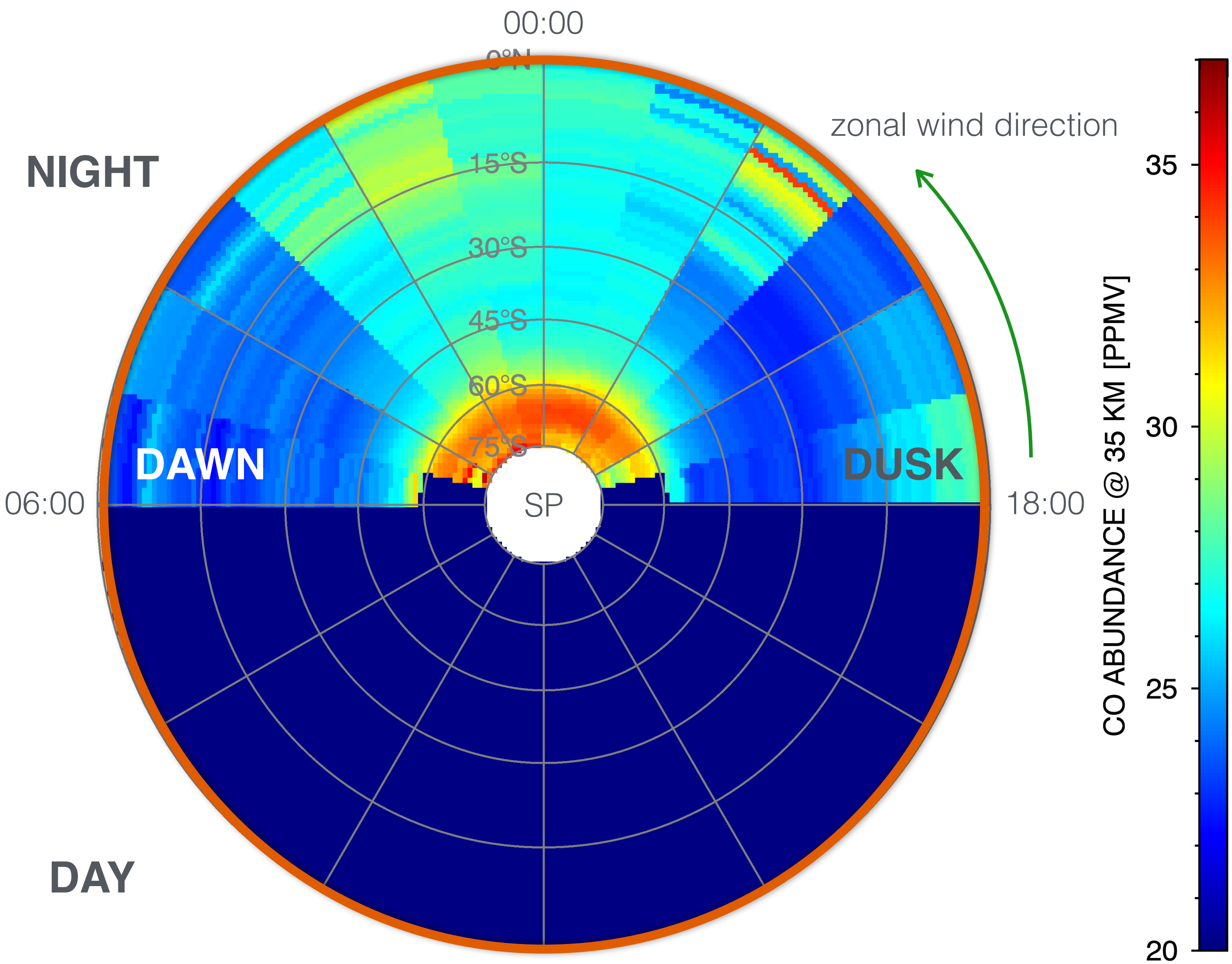
Data Procedure: Emission angle < 85°, 260°< Incidence angle >100°< (straylight), reject locations $I_{2.29}$<0.02 W/m²/sr/μm (removes cloud ghosting)



Tsang et al., 2009, Icarus

RESULTS: LATITUDE AND LOCAL SOLAR TIME

CO ABUNDANCE

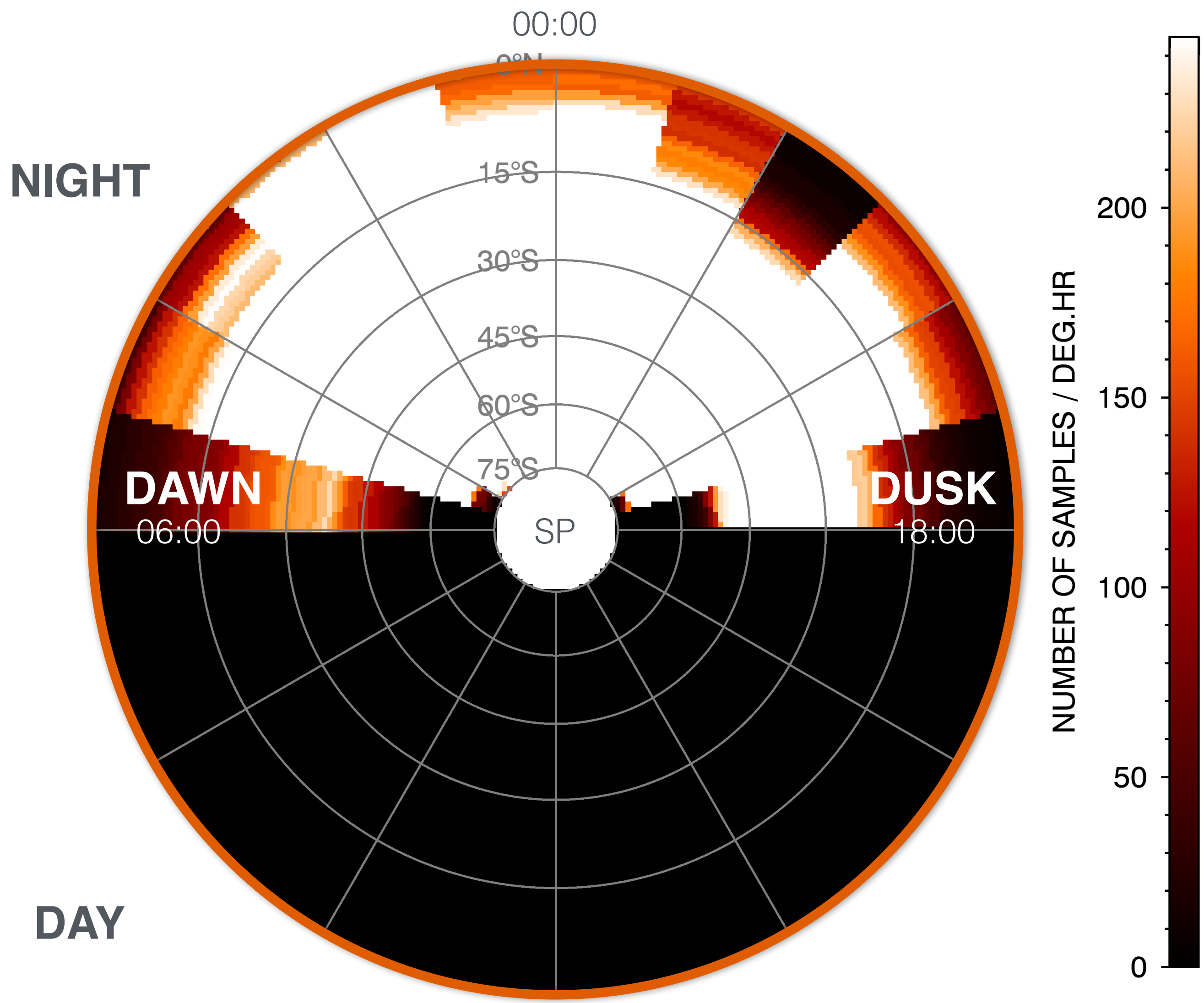


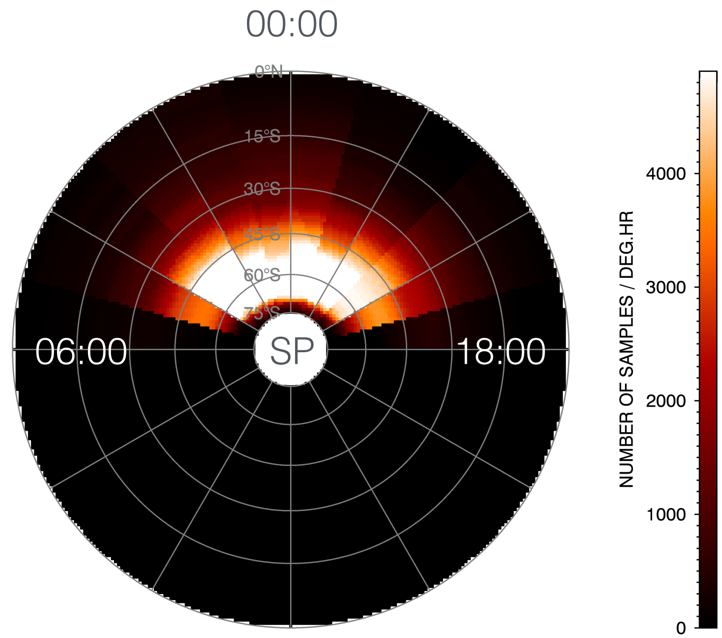
Q: *Is there a relationship between local solar time and CO abundance?*

R: Equator to pole gradient as expected, peaking at 65°S, slight preference to increased CO on the dusk hemisphere c.f. dawn hem., and some anomalous values

RESULTS: LATITUDE AND LOCAL SOLAR TIME

COVERAGE

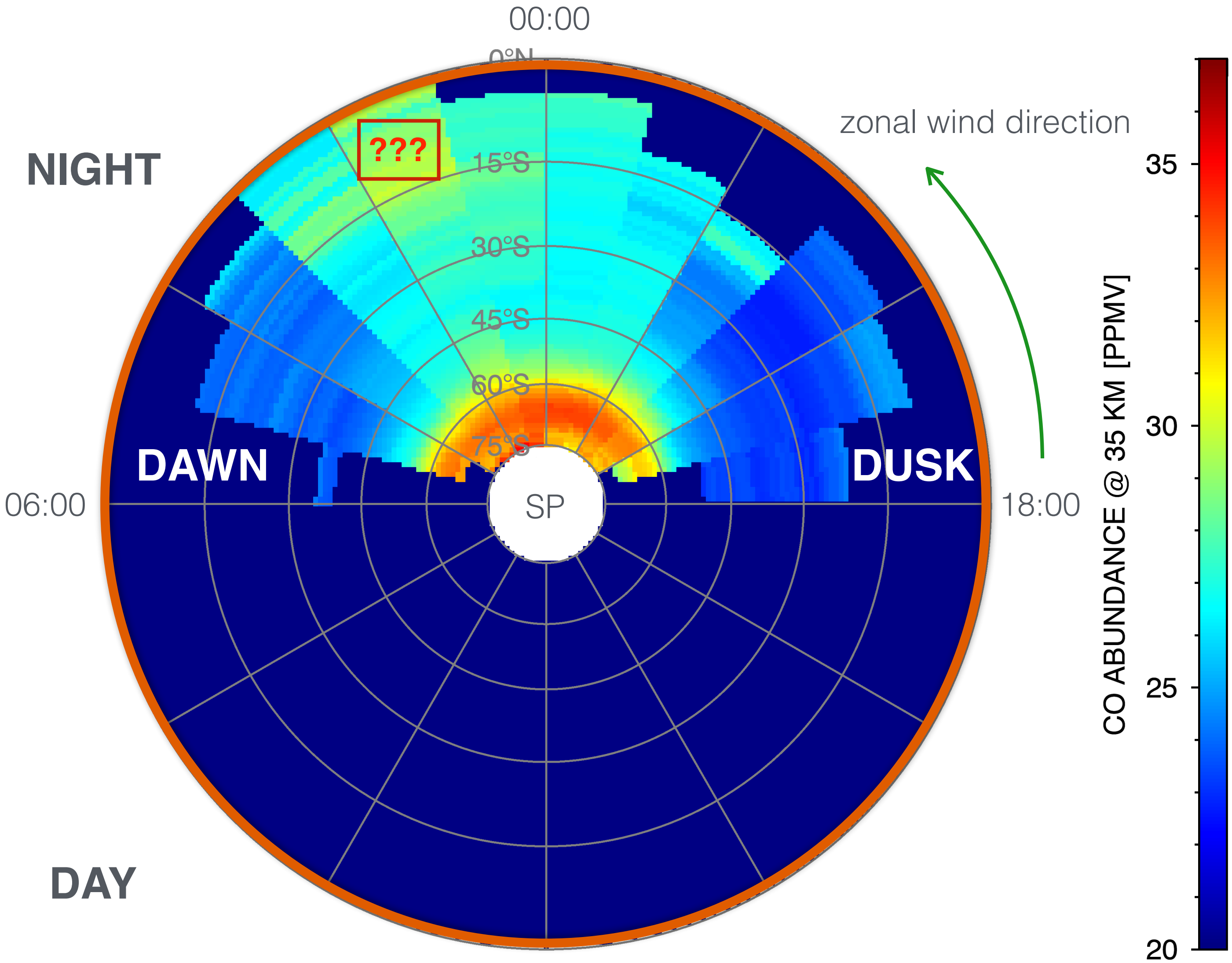


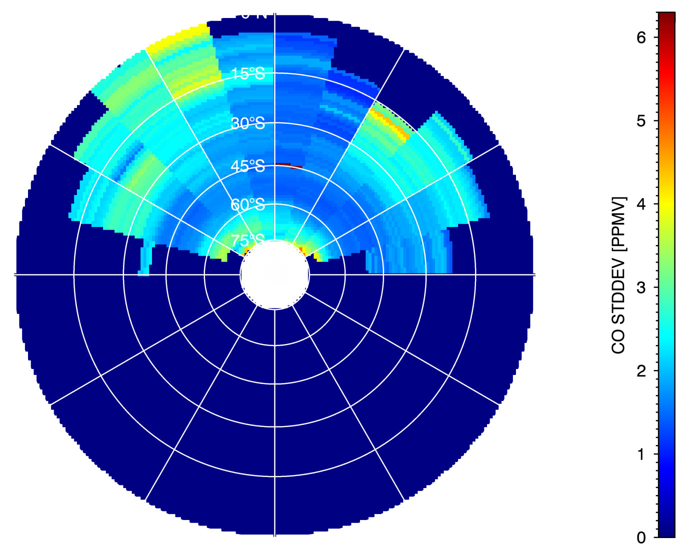


Coverage map is important to access apples-to-apples comparison, but always compounded by difference between equator and pole sampling

RESULTS: LATITUDE AND LOCAL SOLAR TIME

*CO ABUNDANCE > 200 points per (1° lat * 1 hr)*

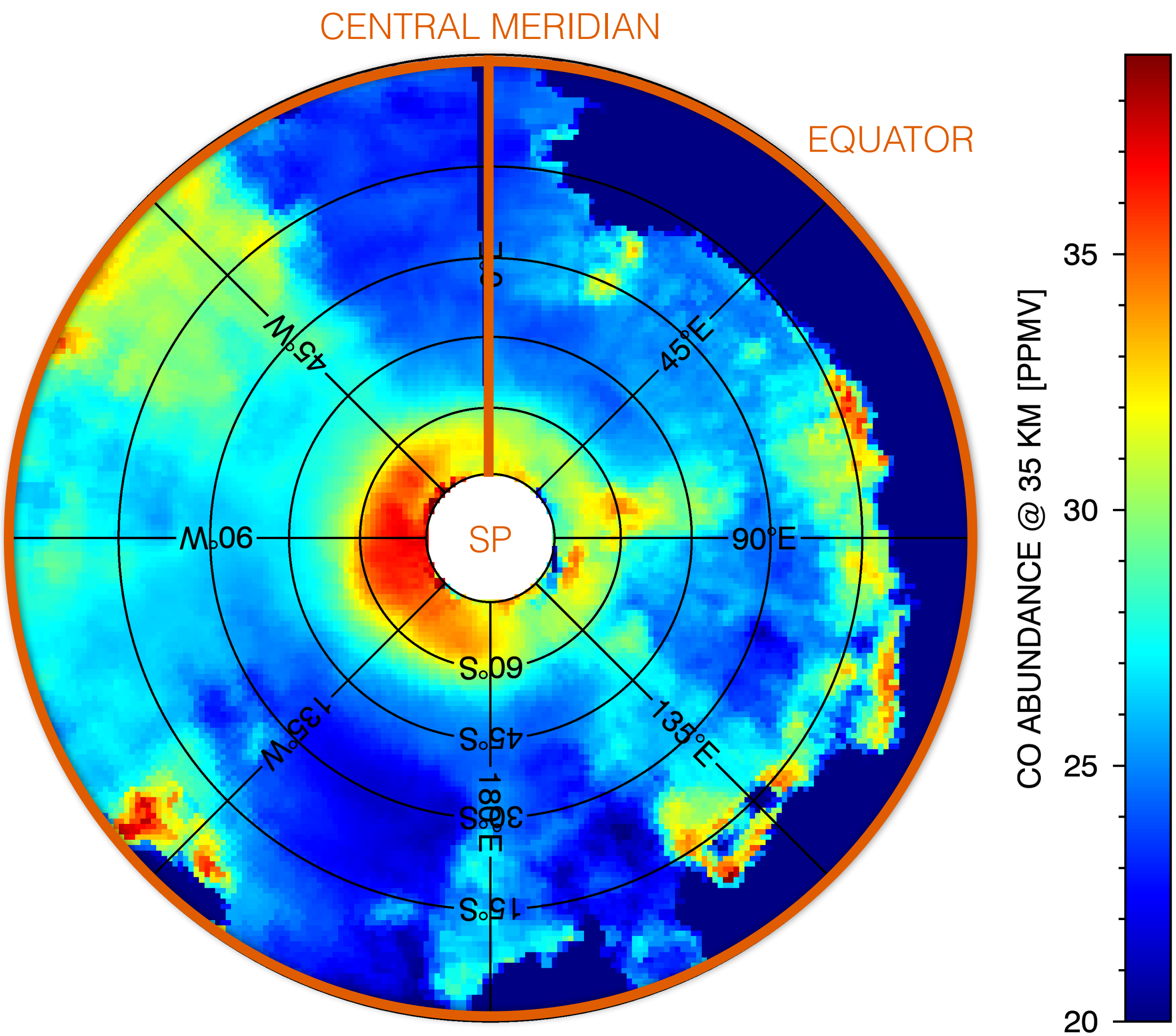




True variability at ??? because 'good' statistics and stddev. shows changes in those bins.

RESULTS: LATITUDE vs. LONGITUDE

CO ABUNDANCE



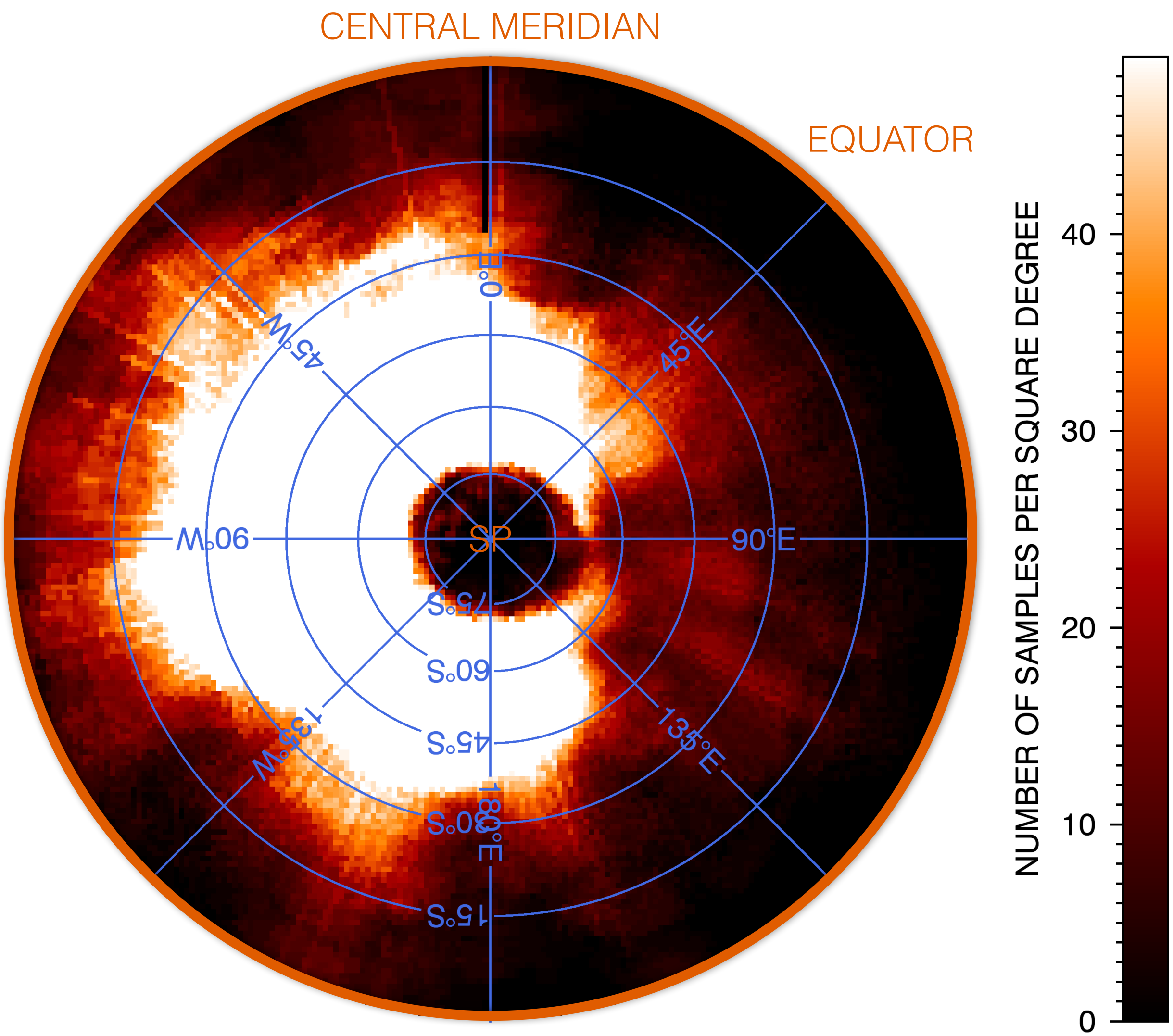
Q: *Is there a relationship between longitude (topography) and CO abundance?*

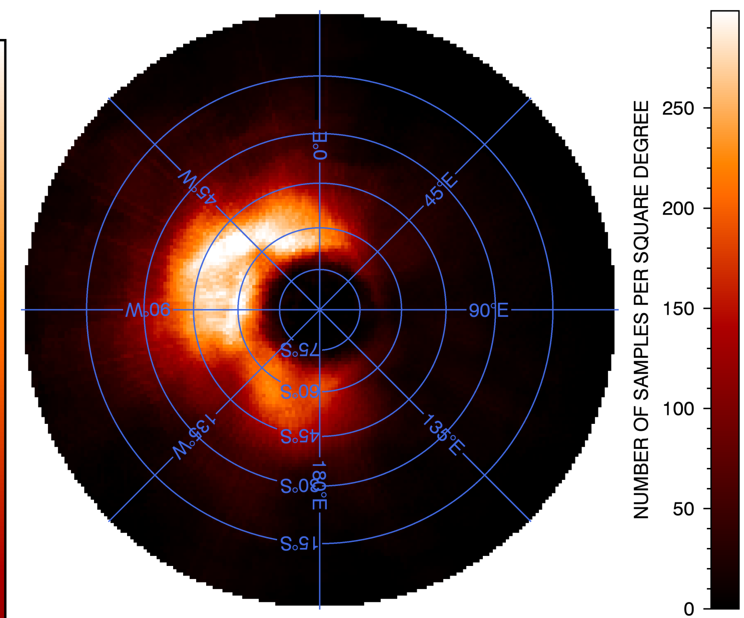
R: Pole to equator gradient as expected, large difference in the western poles, and lots of anomalous values

What about coverage?

RESULTS: LATITUDE vs. LONGITUDE

CO COVERAGE

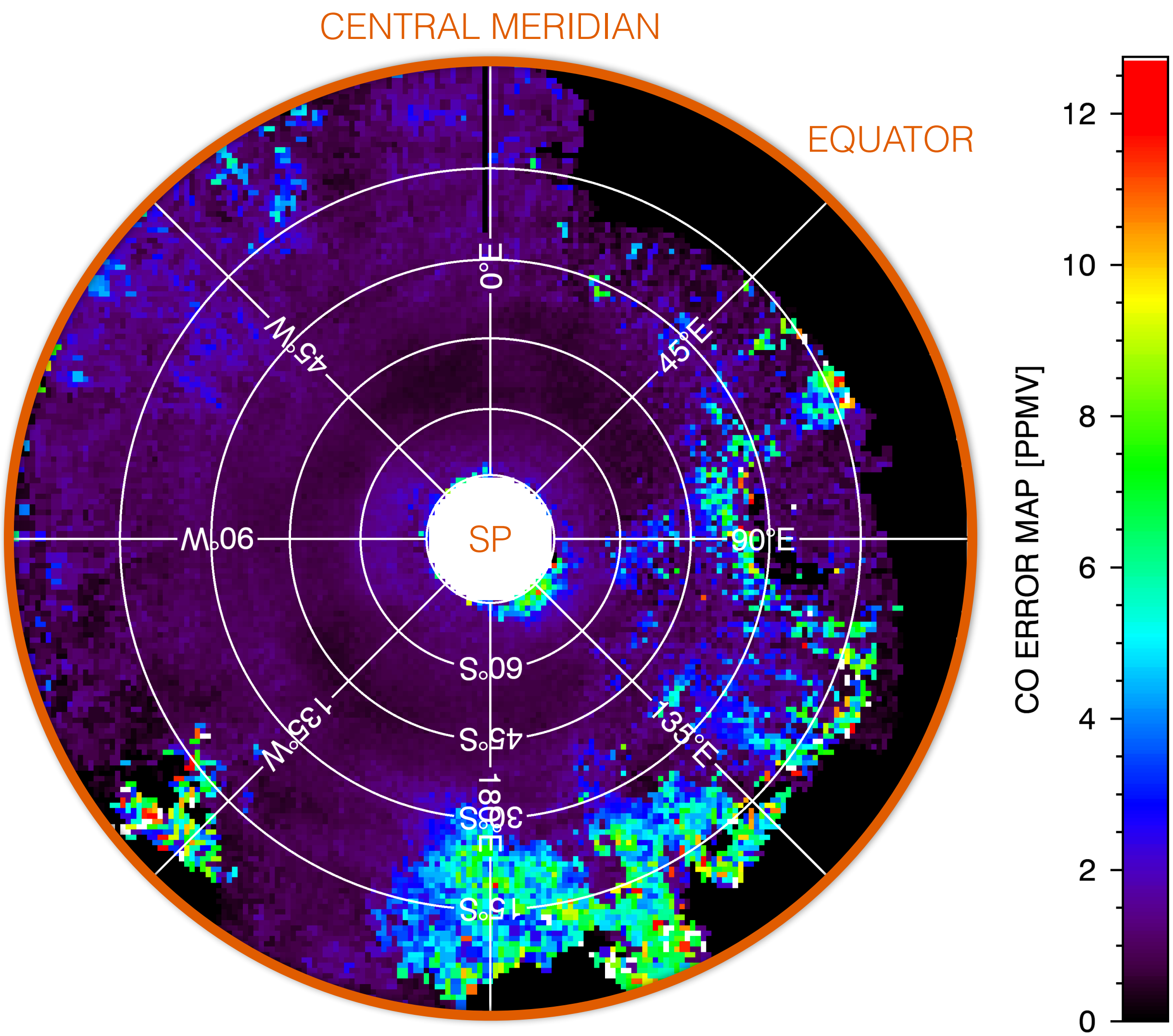




Coverage map is important to access apples-to-apples comparison. Big difference in sampling between 0° - 180° and 180° - 360° longitude.

RESULTS: LATITUDE vs. LONGITUDE

CO STDDEV

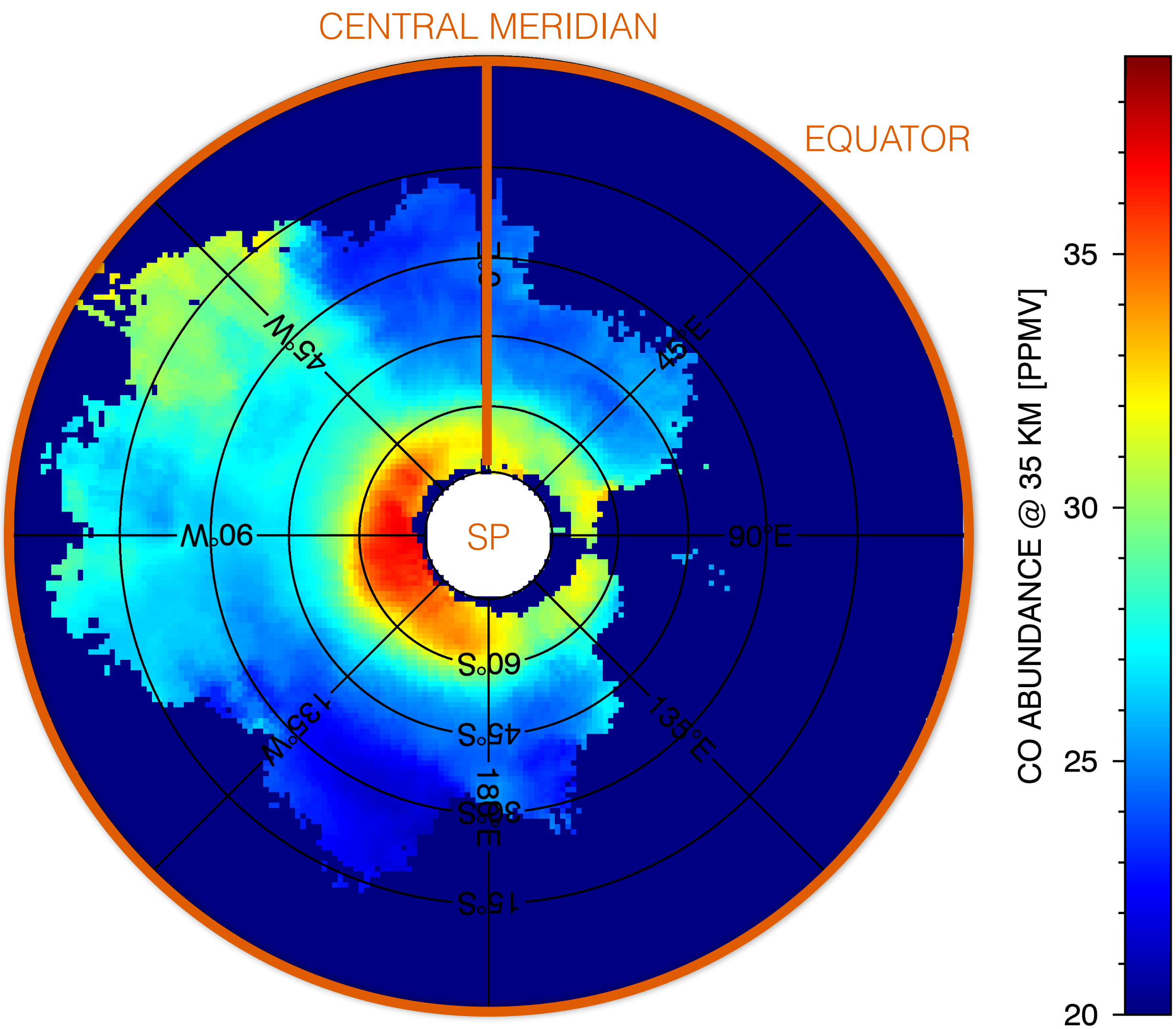


Looks like weather radar…

Deviation from the mean. Indicates variability, which can be tied either to true variability in the atmosphere, or low statistics.

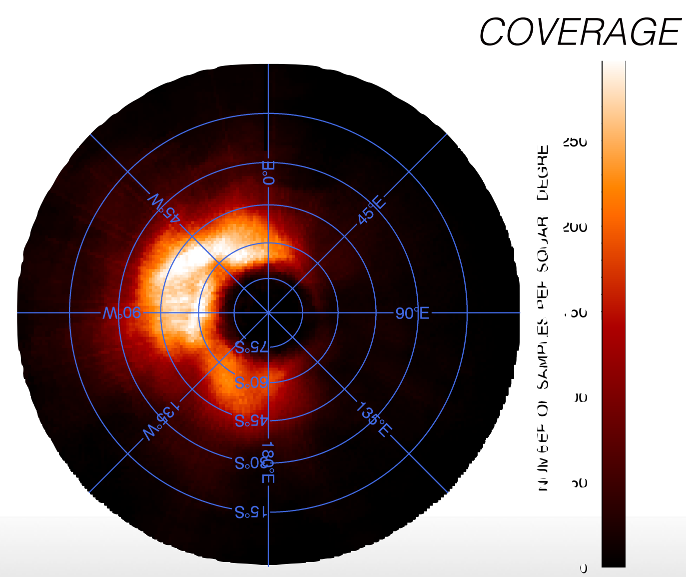
RESULTS: LATITUDE vs. LONGITUDE

CO ABUNDANCE (< 3 ppm STDDEV + > 20 points 1°x1° bin)



Combining the coverage and "error" maps, these are the values we have confidence over.

1) Note polar CO between 180° - 360° is enhanced over 0° - 180°. Also 90°W is stronger than 45°W or 135°W. 45°W equator enhancement



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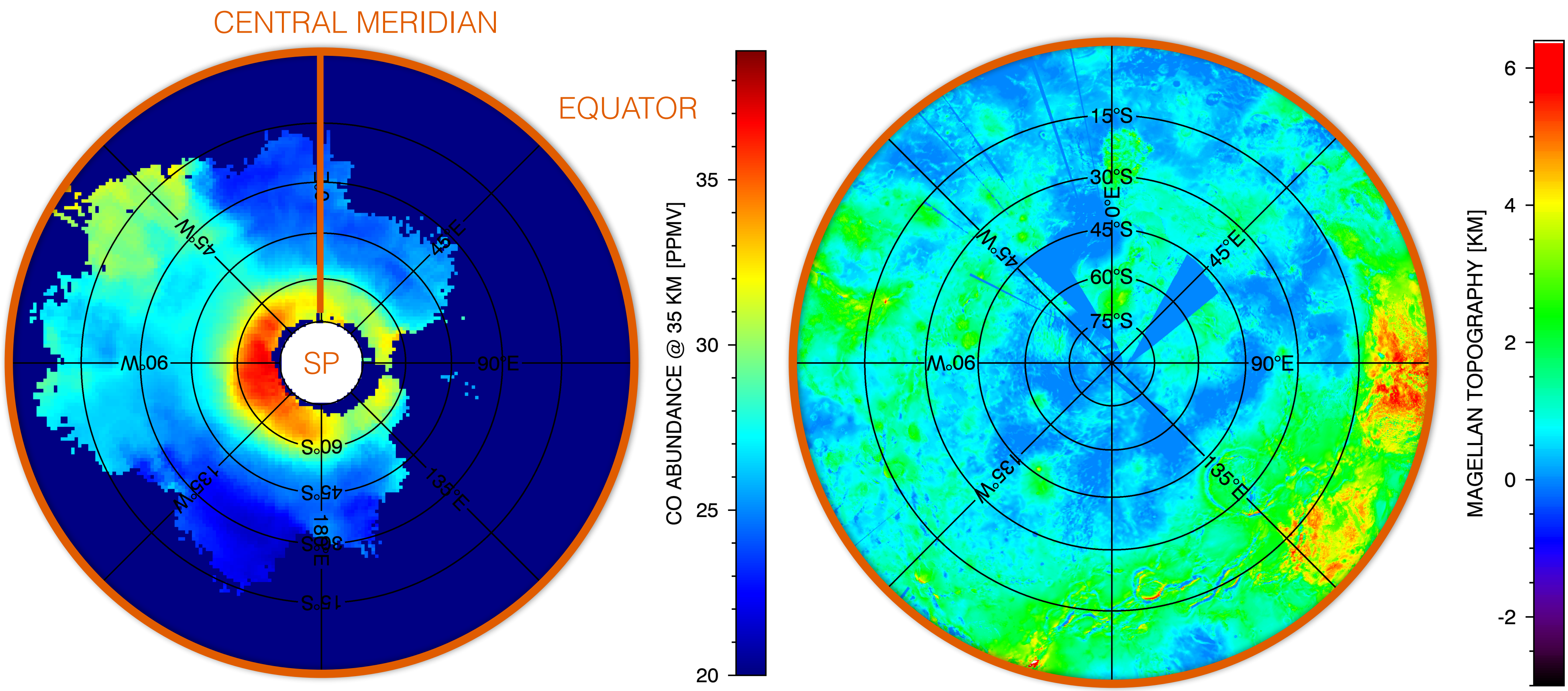
University of Colorado Boulder

RESULTS: LATITUDE vs. LONGITUDE

CO ABUNDANCE CORRELATED TO TOPOGRAPHY??



Inconclusive with these data. But probably not….

Potential topography correlations with increased/stochastic CO midlatitude. Sampling always an issue here, but intriguing especially in light of potential correlations of UV zonal winds with topography (Bertaux et al., 2016)

CONCLUSIONS

- Full Venus Express/VIRTIS-M-IR dataset from April 2006 - December 2009 leveraged for the study of CO 2.32 μm (35 km) nightside NIR in the troposphere. ~2500 spectral image cubes satisfy selection criterion (EA, IA, INT, COD)

- CO ratios (*Tsang et al., 2009)* binned to 1°x1° LAT/LON, 1 hr LST

- LAT vs LST show enhanced CO abundance at poles in the nighttime PM hemisphere cf to nighttime AM hemisphere. Possible variability (slight increase) also seen near the equator (*Marcq, Tsang, Cotton*)

- LAT vs LON shows general pole-equator flow of CO, and some spatial variations. Potential topographic correlations?

- LAT vs. TIME shows a lot unexpected structure TBC (CO Bulge, CO shut down, and enhancement)

- Shows Hadley circulation (or at least deep atmospheric structure) is complicated and not yet well understood.