"Coordinated HST, Venus Express, and Venus Climate Orbiter Observations of Venus", NASA program 12433.

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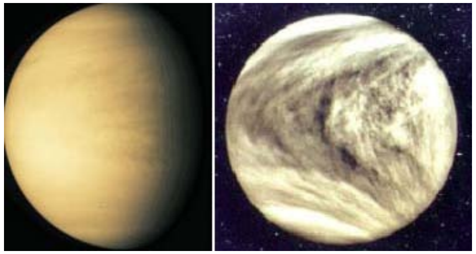
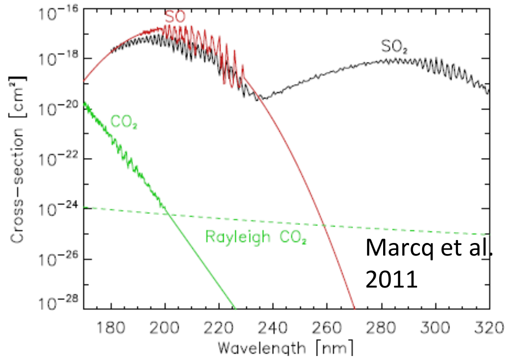
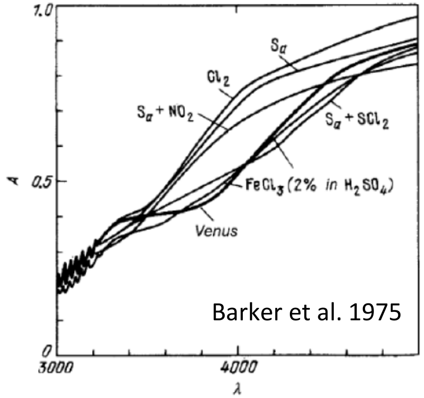
Overview of Program Goals and Motivations

Observation Plan: Use Hubble's Space Telescope Imaging Spectrograph (HST/STIS) to obtain high spatial and spectral resolution spectra of Venus in the 200-600 nm region to track the spectral signature of Venus' UV absorbers @ 65-75 km (i.e., the cloud top level) as a function of latitude and time of day



270 nm **380 nm**





Science Goals:

• quantify SO_2, SO gas density present within Venus' cloud tops as a function of latitude and time of day

• quantify spectrally the opacity levels between 355-375 nm, and quantify the density and distribution of the unknown UV absorber

•Track aerosol distribution as function of latitude and time of day

Science Motivations:

•Obtain data needed to enhance our understanding of the chemical and dynamical processes dominant in Venus' middle atmosphere

•Obtain data needed to assess the impact of sulfur volcanism on the atmosphere of Venus

• Obtain data that can be used to enhance the science return of the VEx and Akatsuki missions.

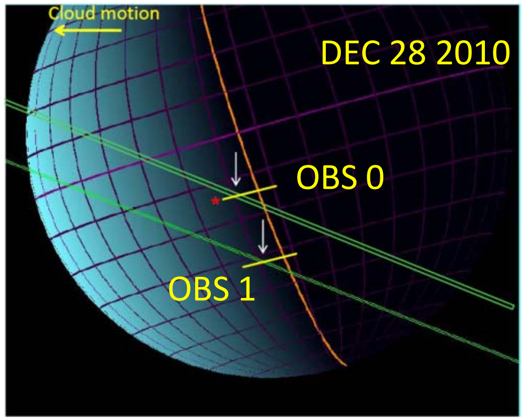
Talk Road Map:

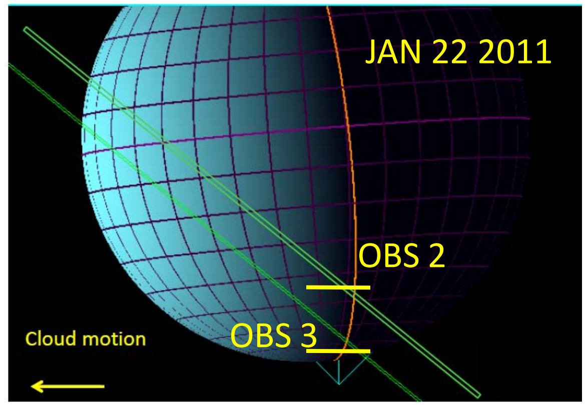
Discuss retrieval and preliminary analysis of 200-300 nm data :

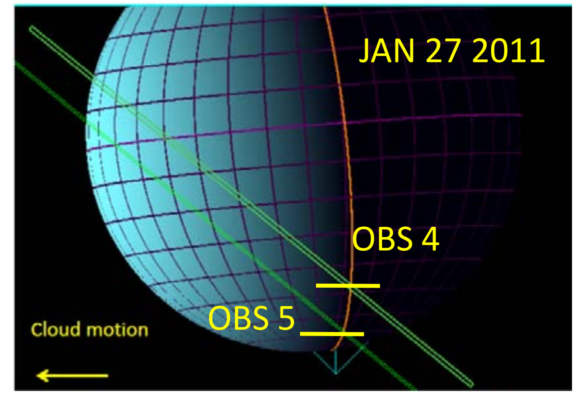
- Discussion of the observation details
- Presentation of reduced 200-300 nm data
- Overview of Retrieval Methods
- Presentation of Preliminary Gas density results
- Discussion
- Future Plans

HST/STIS G230LB (200-300 nm) Observation Details

HST requires Venus observations be taken at a solar elongation > 45 deg. Our observations extend from the morning terminator towards noon. For each date the sub-solar longitude is on the backside of Venus. For each observation the slit is centered at the terminator longitude. For each schematic the orange line is the sub-earth longitude.







OBS 0: 15S, 65L DEC 28
OBS 1: 32S, 65L DEC 28

OBS 2: 45S, 145L JAN 22
OBS 3: 65S, 145L JAN 22

OBS 4: 45S, 160L JAN 27
OBS 5: 45S, 160L JAN 27

Dates of observation were coordinated with the orbit schedule of the VEx and Akatsuki missions

***12/28 HST observations* taken** between 0-2 UT: coordinated with VEx/SOIR and VEx/VIRTIS-M airglow observations
1/22 HST observations taken between 17-19 UT: coordinated with planned Akatsuki UV imaging
1/27 HST observations taken between 15-17 UT: coordinated with planned Akatsuki + VEx UV imaging, and VEx low spectral resolution UV –visible spectral mapping

Data Acquisition and Reduction Challenges

- HST cannot look at the Sun.

- The Venus observation window is 5 min. In the limited observing window spectral and imaging observations cannot be obtained simultaneously

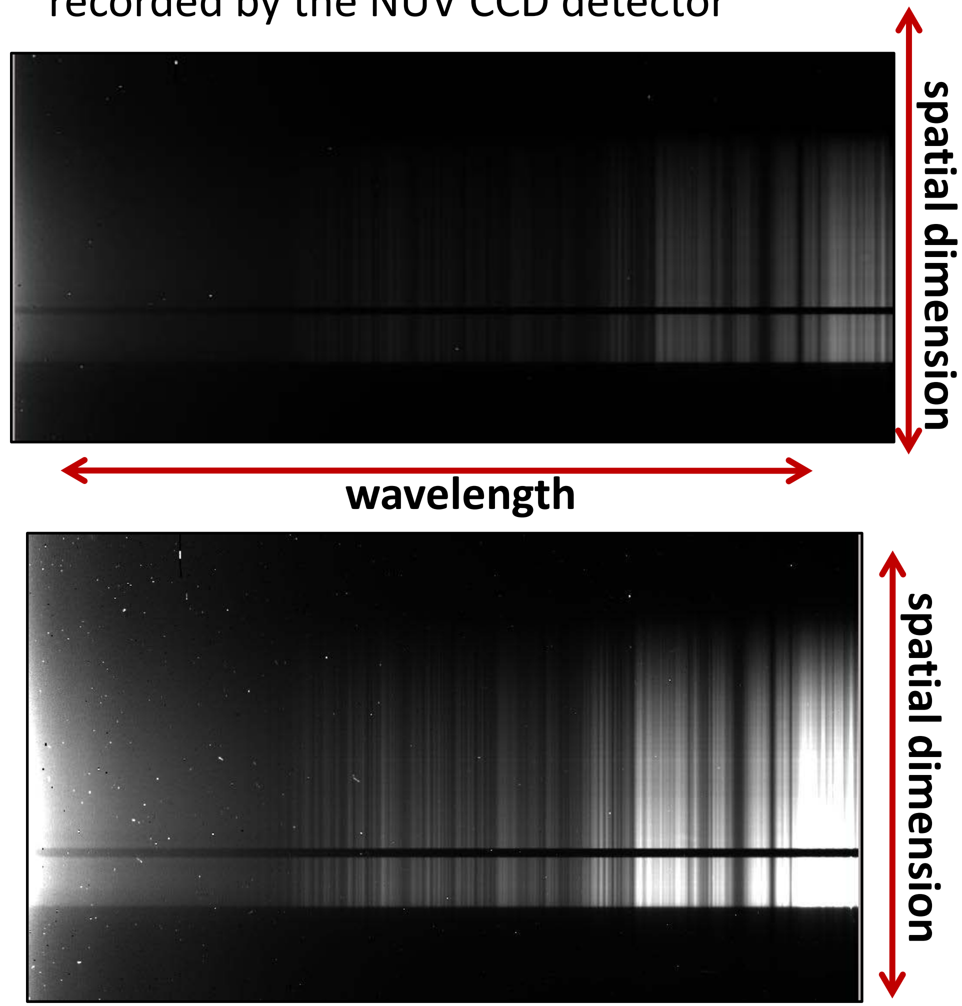
- The observations were obtained with NUV/CCD detector ***notorious*** for sensitivity to both cosmic rays and grating scattered light.

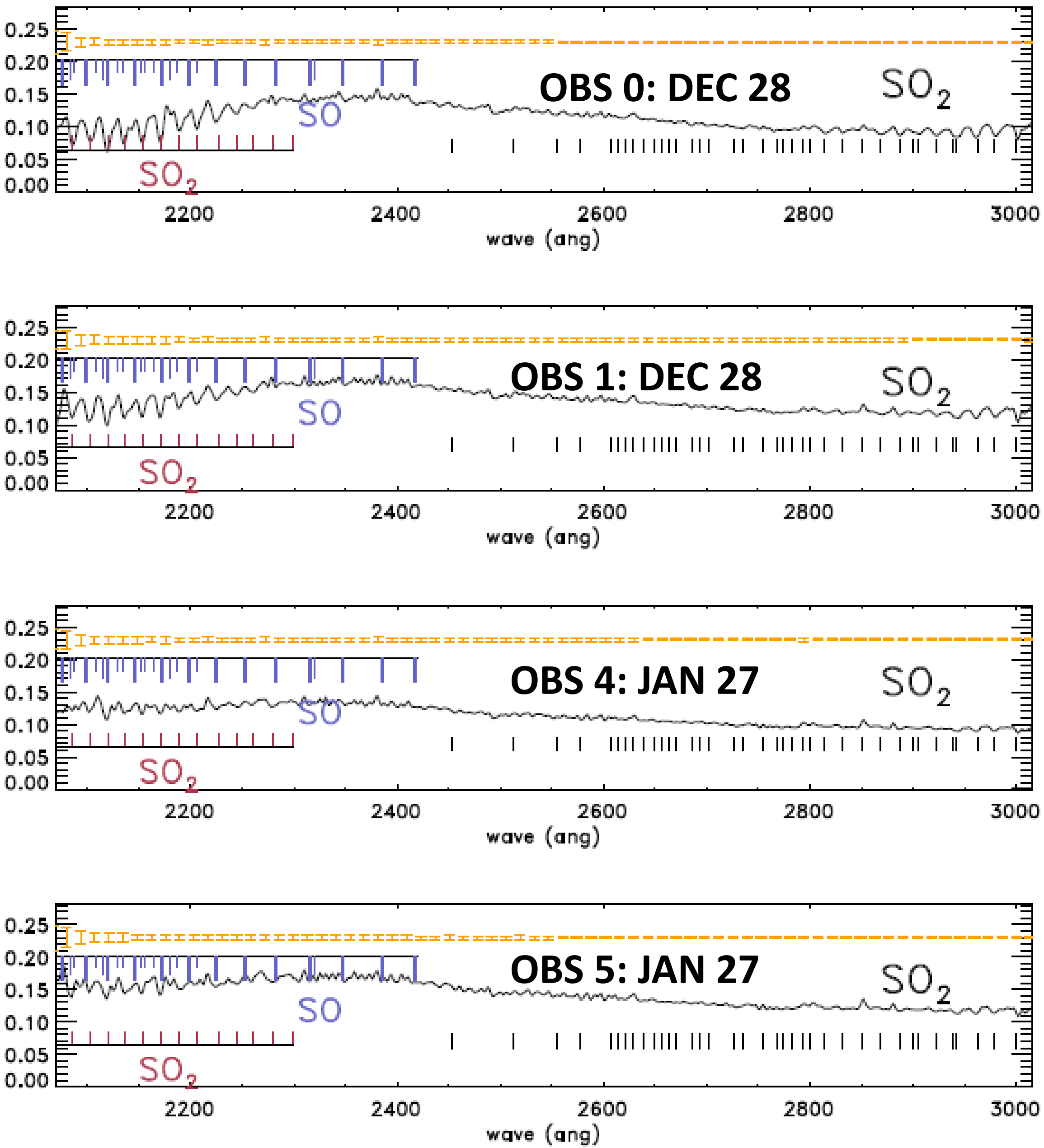
- The limited observing window does not allow time to take a full scan of Venus from 200-1050 nm (needed to straightforwardly map the grating scattered light).

- The limited observing window does not allow for image splitting (needed to straightforwardly remove cosmic rays).

- There was a significant level of background light that needed to be removed.

Raw HST/STIS spectral image of Venus taken with the G230LB grating and recorded by the NUV CCD detector



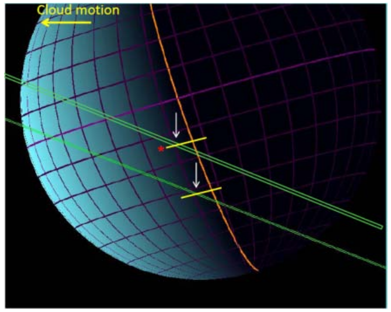


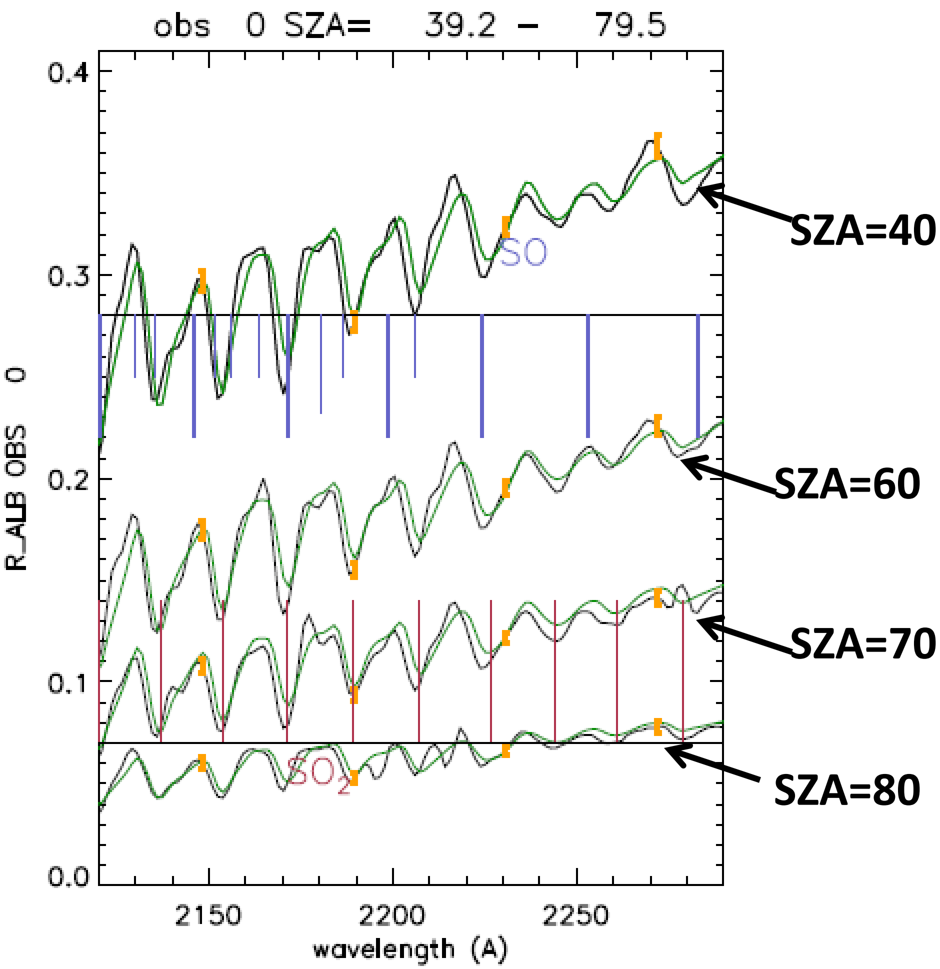
After much effort we successfully reduced the 6 orbits of HST data (OBS 0-5).

In each case we successfully recorded Venus' albedo signature from morning terminator to near noon covering SZA ranging from ~20 to 80 deg.

On the left we show the quality of the SO_2 and SO gas signatures recorded at SZA=70

Gas Density Retrieval Methods





For each observation the data was **binned spatially along the slit every 6 pixels**, total of 56 individual spectra per day providing continuous limb-to terminator data on Venus at ~ 150 km resolution.

As an initial starting point, for each date of observation we choose **5 representative SZA** values ranging from 20-80.

The representative SZA were chosen to provide the greatest contrast in the observed limb-to-terminator gas density signatures.

The gas densities were retrieved based on fitting the short wavelength (2100-2300 A) region of the spectrum

--S/N highest above 2100 A

--region where data available for both the SO and SO_2 gas absorption cross-section data

Gas Density Retrieval Methods

To obtain the SO and SO_2 gas densities we use the updated and improved RT code developed by Marcq et al. 2011

Model Updates

• SO_2 absorption cross-sections (and temperature dependence) derived from recent high-spectral resolution laboratory measurements taken at multiple temperatures (160 K, 198 K, and 295 K), by the same instrument and with near identical spectral sampling and resolution (Rufus et al. 2009, Blackie et al. 2011, Stark et al. 1999, Rufus et al. 2003)

•Extended SO cross-section data to include lab data obtained by Nishitani, et al., (1985); used medium-spectral resolution SO absorption cross-section measured by Philips et al. (1981) at 300 K.

Additional model inputs:

•P(z) and T(z) from VIRA-2 (50 to 110 km)

•Rayleigh cross-sections of N_2 and CO_2 from Sneeps & Ubachs (2005)

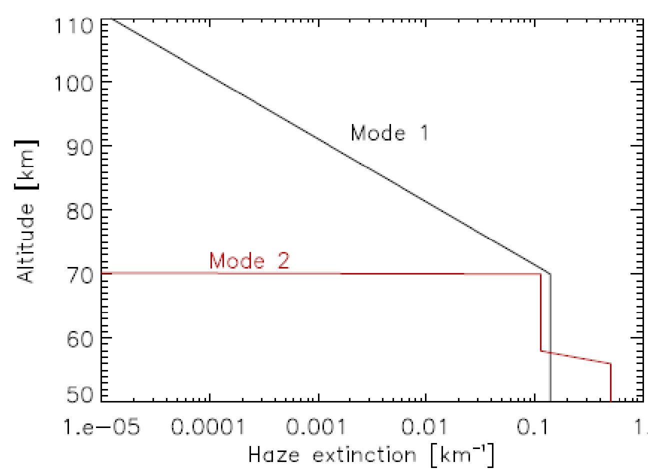
•CO_2 absorption cross-section (and temperature dependence) from Parkinson et al. (2003)

•Bimodal aerosol distribution (r1 = 0.24 μm, r2 = 1.1 μm).

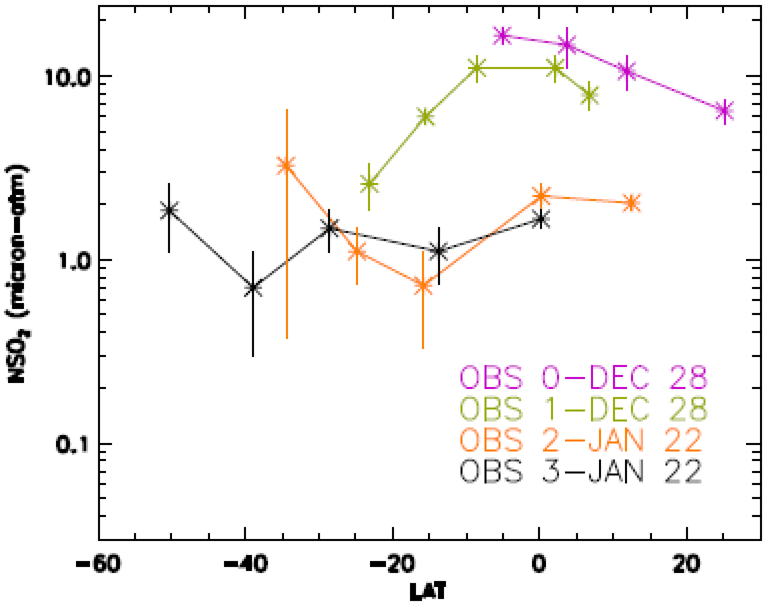
•g(λ), ϖ_0 (λ) and phase functions from Mie theory

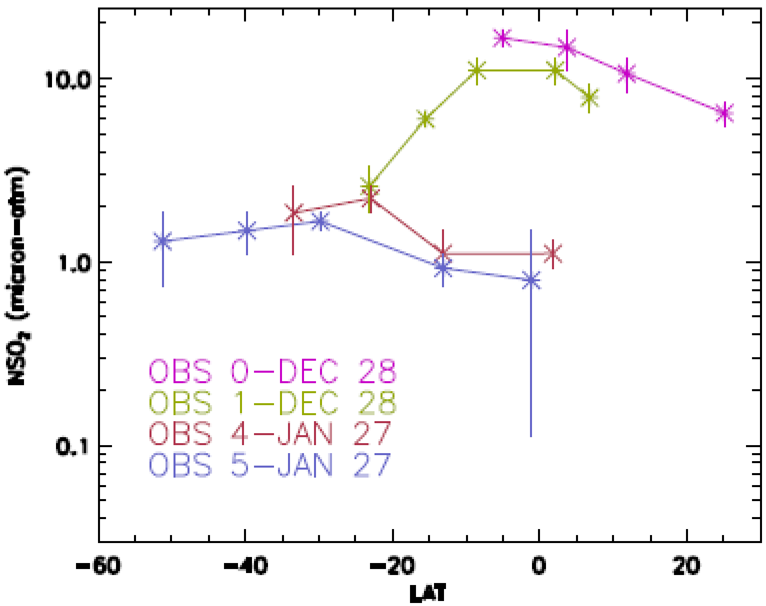
•Aerosol vertical profile

Mode 1			
	$\tau_1(z > UCB)$		variable (less than 2)
	$H_1(z > UCB)$	[km]	4.28
Mode 2			
	Upper Cloud Boundary (UCB)	[km]	72
	$\tau_2(50 < z < 56\ \mathrm{km})$		9.72
	$\tau_2(56\ \mathrm{km} < z < UCB)$		5.12
	H_{SO_2}, H_{SO}	[km]	3



Initial Results





Preliminary SO_2 gas density results (in micron-atm).

Temporal variation in absolute SO_2 gas density between DEC 28 and Jan 22 and Jan 27 evident.

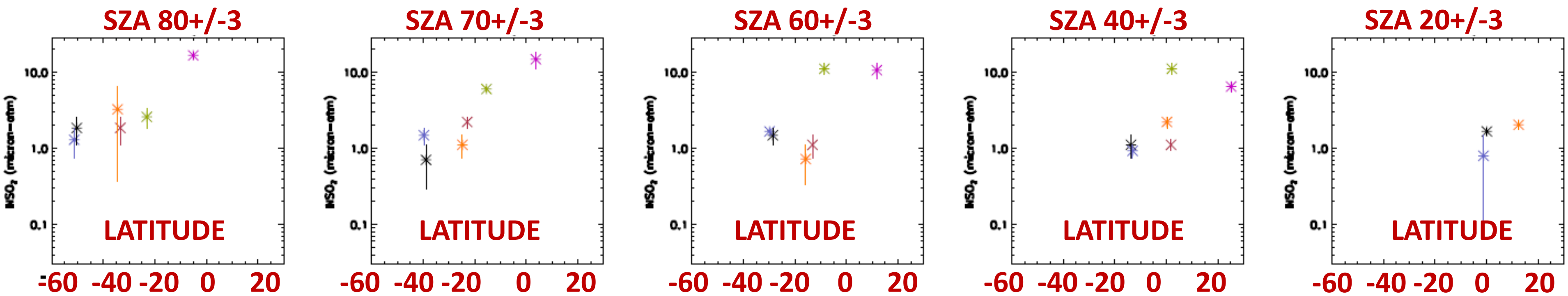
Highest SO_2 densities seen DEC 28, 2010

DEC 28, JAN 22 show increase in gas density from 25 N to equator

DEC 28, JAN 22 decrease between 10 S and 15 S

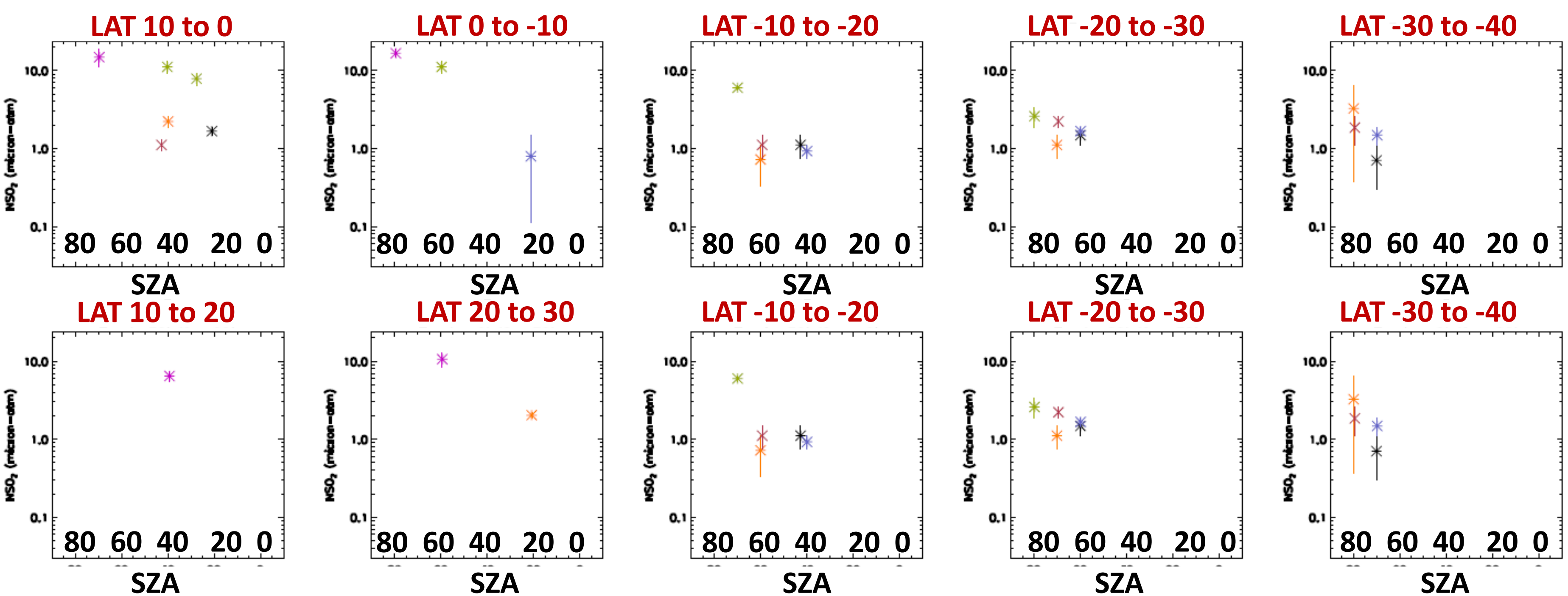
JAN 27 remains stable between 10 S and 15 S, but then decreases after 20 S

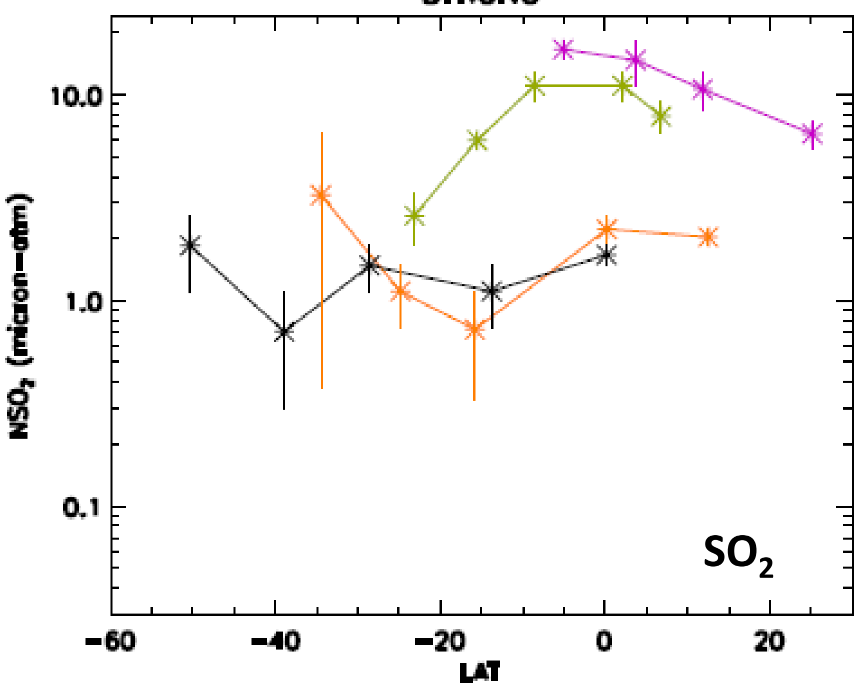
Because our slit is angled, latitude and time of day variations are co-mingled. Binning SO_2 results by SZA vs. multiple LAT clarifies trends in SO_2 gas density behavior



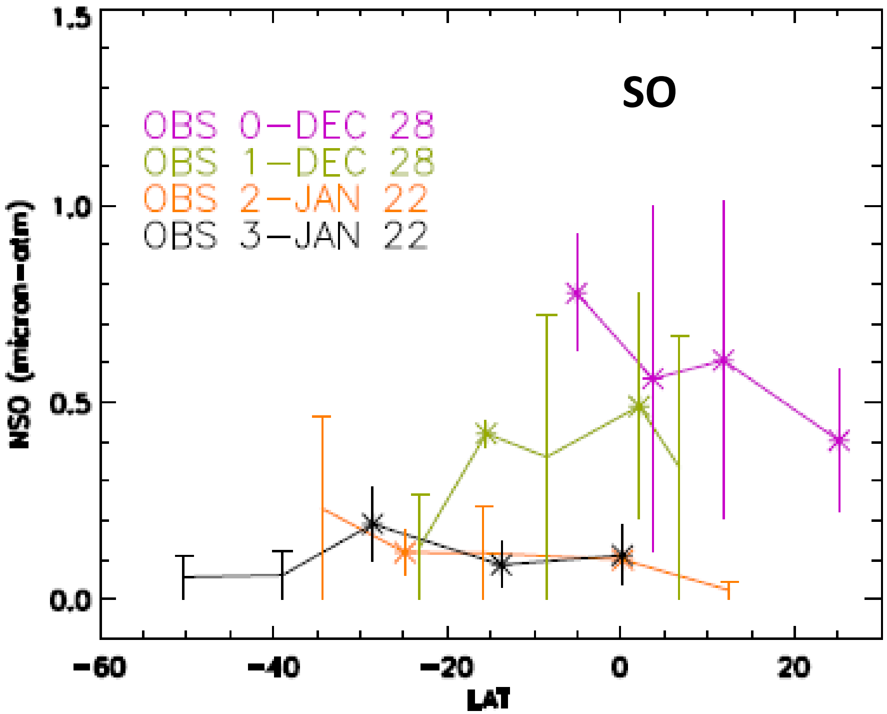
For each SZA bin ***the maximum SO_2 gas density is consistently located in equatorial region***.

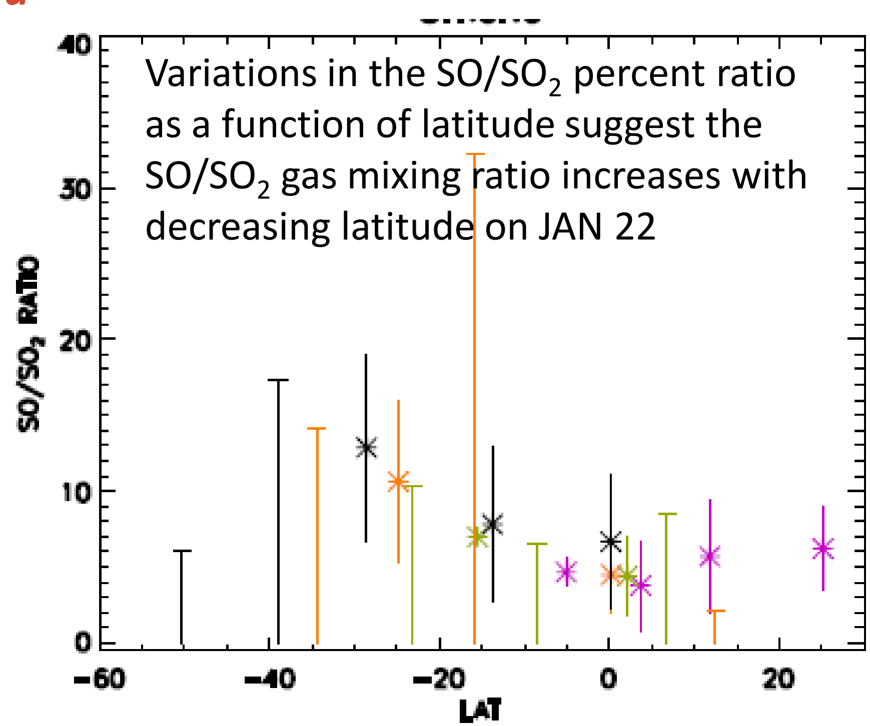
Binning SO_2 results by LAT vs. multiple SZA indicates for each latitude bin the ***SO_2 gas density decreases as the SZA decreases*** (i.e. moving from morning terminator towards noon):

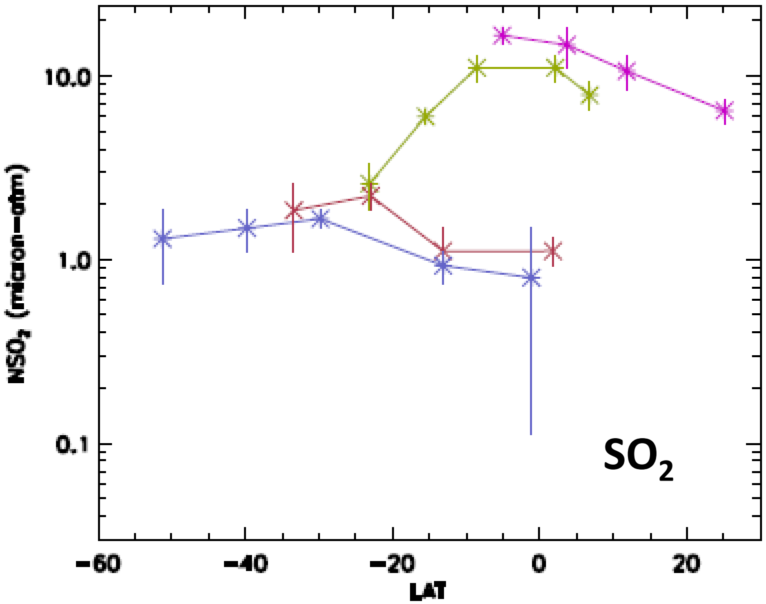




Preliminary SO gas density results (in micron-atm):
Photochemistry predicts SO gas to increase as SO_2 decreases, if SO_2 photolysis is the only source.
Observations indicate:
•On **DEC 28** (**OBS 0+1**): SO gas density variation relative to the SO_2 gas density variation is somewhat chaotic, but ***basically the SO is observed to increase and decrease in parallel with the SO_2 gas***
•On **JAN 22** (**OBS 2 +3**) variation in the SO gas density from 20N to 30 S parallels SO_2 gas behavior.
•These results suggest that the SOx system is not closed





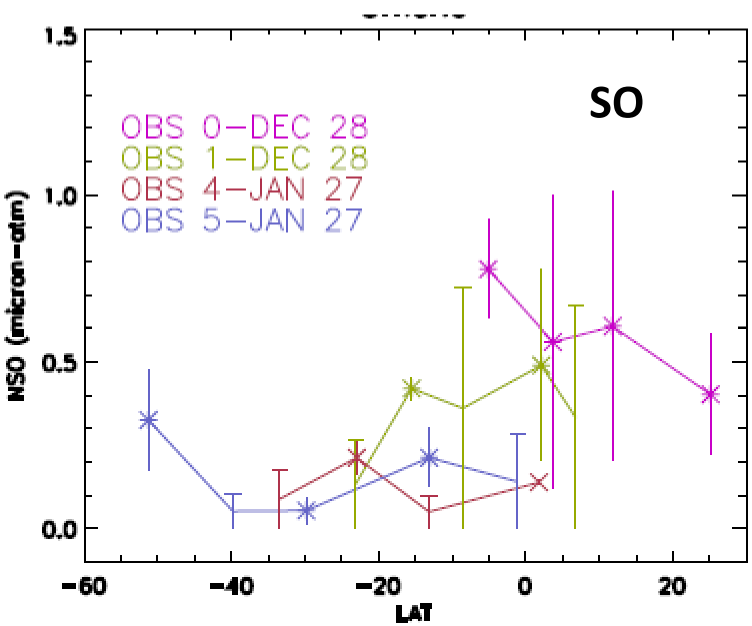


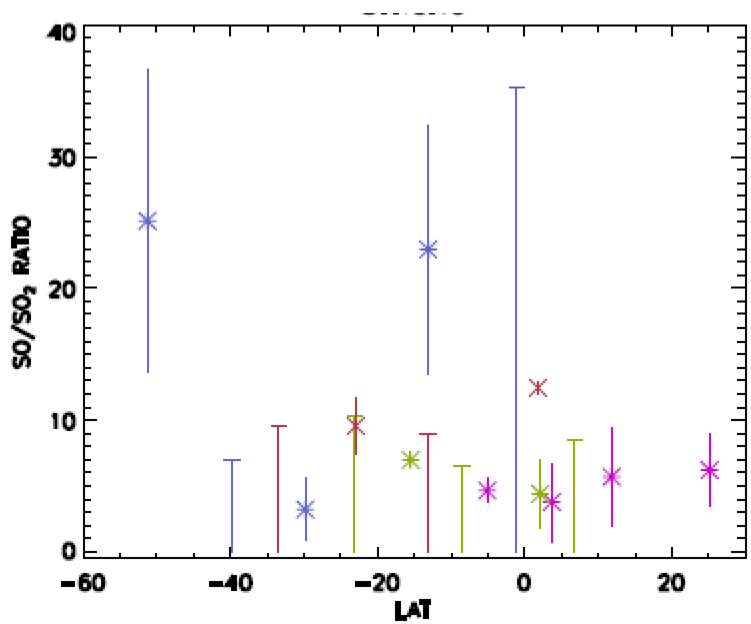
•On **Jan 27**, **OBS4** ***SO gas density observed to follow changes in SO_2 gas density***

•**On Jan 27**, **OBS 5** ***SO gas density decreases when SO_2 increases and vice versa***.

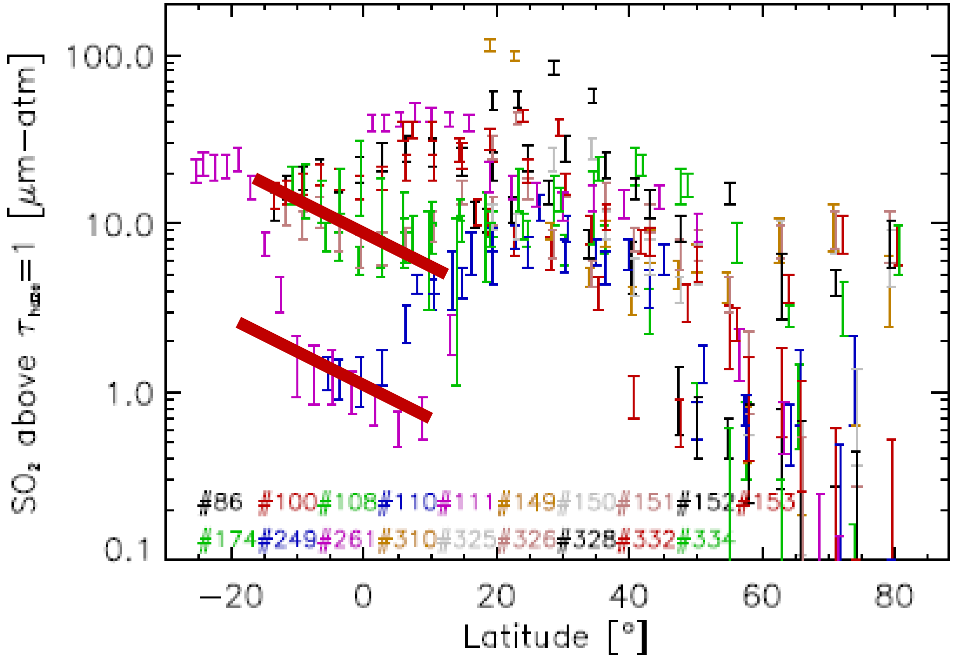
•On **DEC 28** (**OBS 0+1**) ***the SO/SO_2 ratio is the lowest at the equator and observed to increase with increasing N/S latitude***.

•On **JAN** (**OBS4** + **OBS 5**) latitudinal variation in the ***SO/SO_2*** ratio ***does not follow the pattern recorded in either of the two previous observations.***

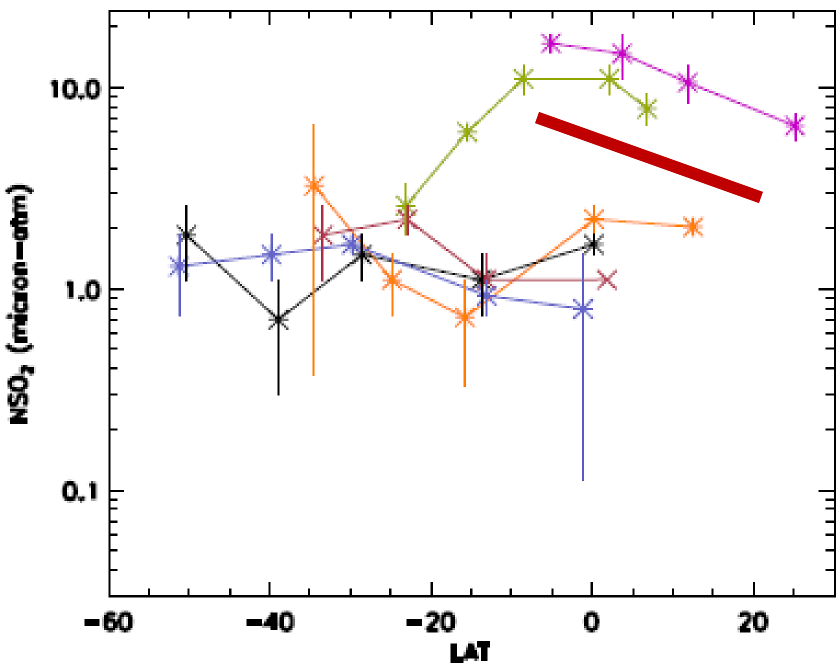




Latitudinal coverage of the HST and VEX/SPICAV observations overlaps between 25N and 25 S latitude



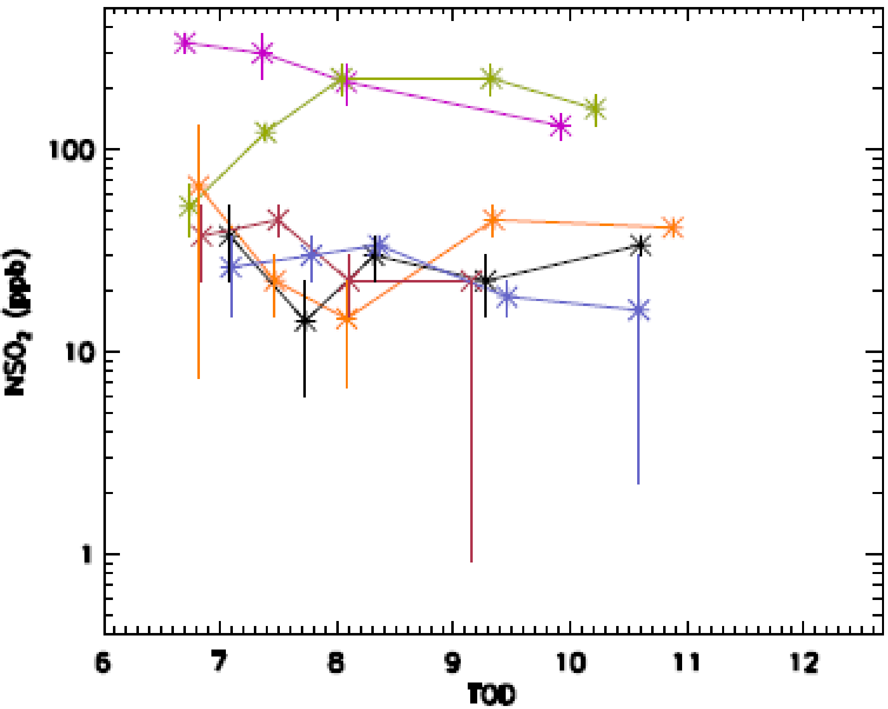
SO_2 gas densities inferred from Vex/SPICAV nadir viewing observations between 25N and 25 S range from ~ 0.7-110 micron-atm which translates to ~10-450 ppb.

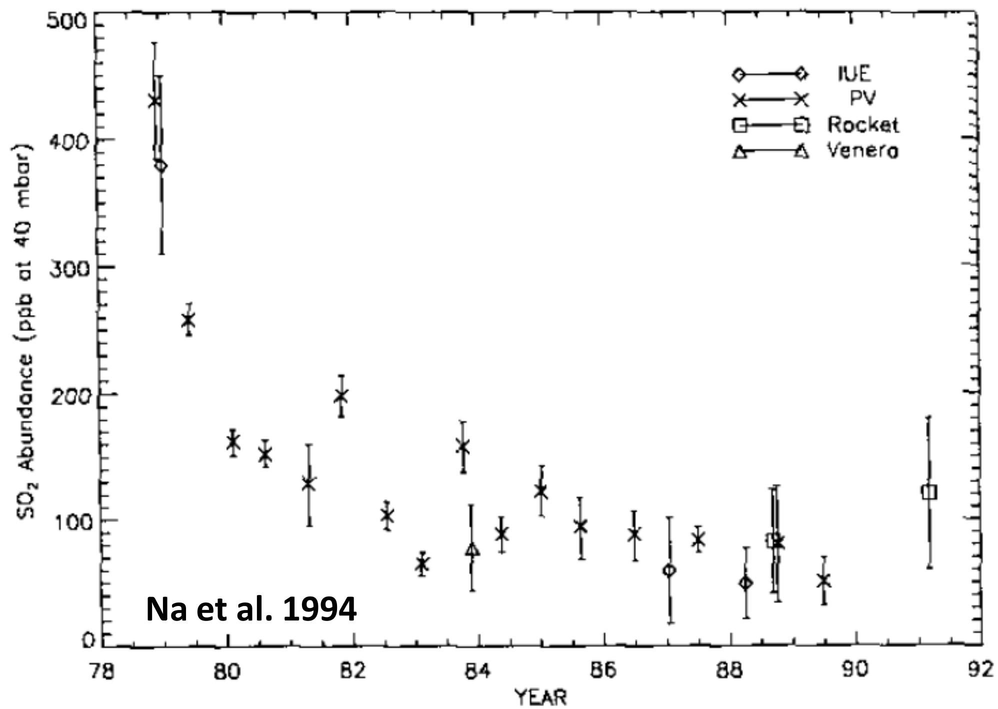


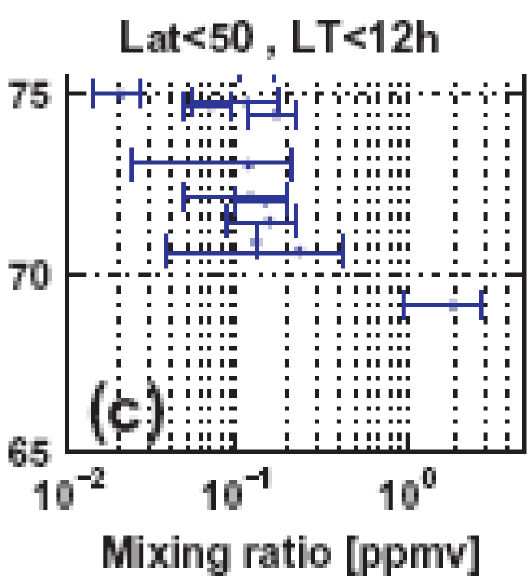
Between 25N and 25 S HST inferred SO_2 gas densities ~ range from ~1-20 micron-atm (or ~10-350 ppb).

HST derived SO_2 mixing ratios are comparable with values derived by SPICAV nadir (Marcq et al. 2011)

HST observations record an increase in the SO_2 gas density from ~15 N to -10 latitude. Appears consistent with some single orbit trends seen in the VEx/SPICAV nadir observations







Belyaev et al. 2012

In general the range of SO_2 mixing ratios derived from the HST observations are consistent with the range recorded in Spacecraft data obtained over the last 30 years.

The values also overlap values derived by SPICAV nadir (Marcq et al. 2011) and SPICAV/SOIR occultation observations obtained 70-75 km (Belyaev et al. 2012).

Summary:

HST/NASA Program 12433 data acquisitions have been successfully completed

•high S/N spatially and spectrally resolved 200-600 nm observations of Venus' dayside (morning to noon) atmosphere were obtained using HST/STIS on 3 separate dates, covering latitudes 45 S to 25 N

•the variability of the atmosphere was recorded on both short (*5-day*) and long (*1-month*) time scales.

The data obtained with NASA Program 12433 at 200-300 nm have been successfully reduced:

•the albedo level in the 200-300 nm region is accurately defined, subsequent to the removal of all artifacts, background emissions and grating scattered light.

Initial analysis and spectral fitting of the data in the 210-230 nm region indicates:

• the absorption signatures of ***both*** the SO and SO_2 gases are evident in the observed spectra

• the SO and SO_2 gas densities vary with ***both*** latitude and time of day

• the SO and SO_2 gas densities at a given latitude are variable on a time scale of weeks

•the maximum SO_2 gas density is found in the equatorial regions

• the SO_2 gas density decreases with local time from the morning terminator towards noon

• the range of SO_2 gas densities inferred from the HST data is consistent with gas density retrievals obtained previously from Venus Express SPICAV and Venus Express SOIR observations of Venus.

• the SO gas density is **NOT** solely controlled by the photolysis of SO_2 gas

Future work:

•Expand aerosol density constraints, i.e. complete the analysis of the long wavelength data

•Complete a detailed comparison of the simultaneously obtained HST, VIRTIS-M and SOIR data

•Use HST retrieved latitude and time of day SO and SO_2 column density data to calibrate photochemical models

•Use coordinated vertical (SOIR and ground-based obtained) and horizontal (HST obtained) SO_2 column density data to calibrate photochemical models (Looking at the sulfur-chemistry cycle (SOx))

•Compare observations with photochemical model results to assess impact of sulfur volcanism on the atmospheric gas densities.

Future Observations:

•Obtain new HST observations coordinated with VEx and pending Akatsuki orbits; *continue international collaborations*

•Obtain more spatially and spectrally resolved UV data from which we can monitor Venus' SO_2 gas density, while simultaneously building a data base of the SO and aerosol behavior as a function of time **within a full solar cycle** *This data is critical for i) assessing the impact of solar variability on the gas densities; ii) defining the dominant circulation patterns active in Venus' atmosphere; and iii) assessing and distinguishing the role of sulfur volcanism, photochemistry and dynamics on the short and long term variability of the atmospheric gas and aerosol densities*

Acknowledgements:

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