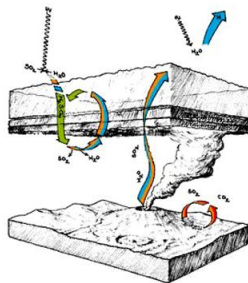
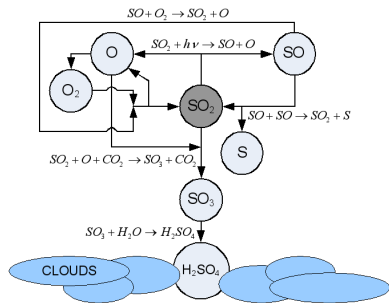




# Why looking at SO<sub>2</sub> ?

- SO<sub>2</sub> linked to:
  - **Geological activity** Long-term ( $\sim 10^7$  yr) source for SO<sub>2</sub> assumed to be volcanic outgassing.
  - **Cloud formation (and energy deposition)** SO<sub>2</sub> is a precursor species to H<sub>2</sub>SO<sub>4</sub> through photo-oxidation
  - **General circulation** Short-term source for SO<sub>2</sub> above the clouds located in lower atmosphere (150 ppmv).



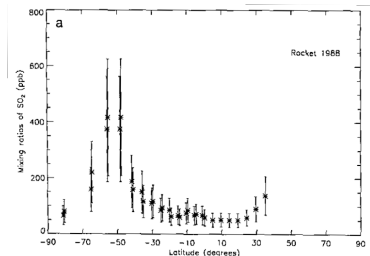
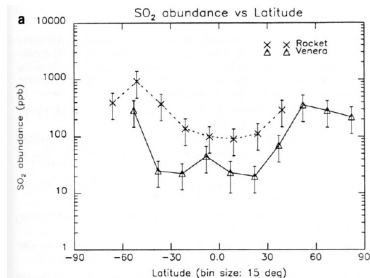


- Venera 15

1993 Zasova et al., IFS:  
**Equator to pole**  
**increasing gradient** (by a  
 factor of  $\sim 10$  at high  
 latitudes ( $> 30^\circ$ ))

- Rocket

1994 Na et al., UV: similar  
 trend. Explained by faster  
 photo-dissociation rate at  
 lower latitudes (lower  
 SZA).



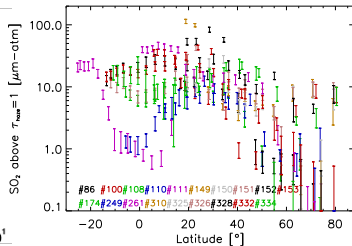
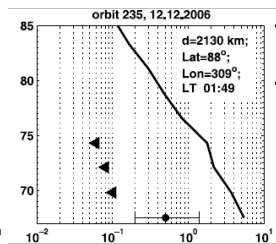
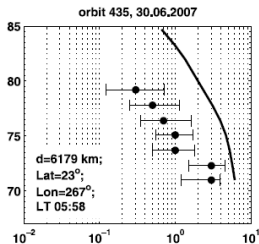
- High levels of SO<sub>2</sub>

2008 Belyaev et al., SOIR:  $\sim 1$  ppmv at cloud top (low latitudes), scale height between 3 km and 1 km.

2010 Marcq et al., SPICAV-UV: similar abundances.

- Latitudinal variations

- Both studies found the latitudinal gradient reversed compared to the 1980s.

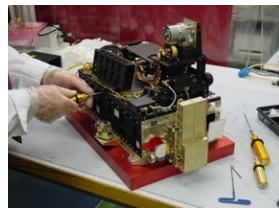


- SPICAV-UV

- 170 – 320 nm, 1.5 nm spectral resolution
- FOV :  $0.24^\circ \times 0.94^\circ$  with slit, spatial resolution  $0.7'$
- **Nadir** mode (**A**ny emission angle)
- **Dayside** ( $SZA < 89^\circ$ )

- About 200 selected orbits

- From orbit #23 to #2100
- Science cases
  - Mostly pericenter and off-pericenter.
  - Latitudinal scans (preferred) or spot-pointing.



- **Model**

- Same as **Marcq et al. (Icarus, 2011)**
- $\sigma(\text{SO})$  needs to be improved!

- **Fitting**

- First guess using a multilinear interpolation on lookup tables.
- Final estimate by running the Fortran model inside the IDL Levenberg-Marquardt routine to retrieve  $N_{\text{SO}_2}$  (SO<sub>2</sub> column density above  $\tau_{\text{haze}} = 1$ ).
- Translation into mixing ratio  $q_{\text{SO}_2}$  at 72km dependent on  $\tau_{\text{haze}}$  profile.

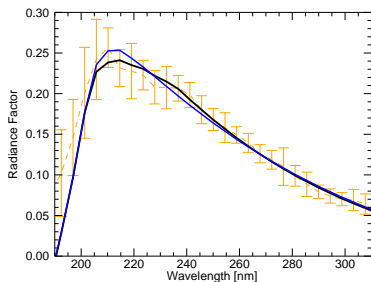


Figure: Fit with  $2 \pm 1 \mu\text{m-atm}$  of SO<sub>2</sub> (#1338)

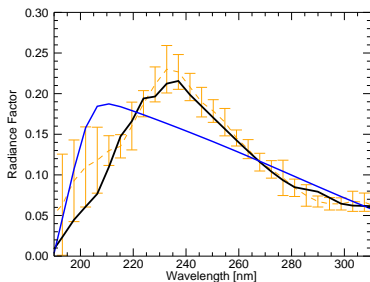
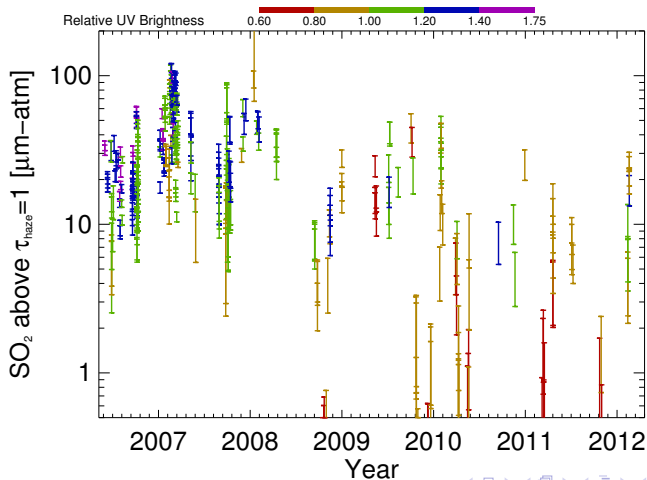


Figure: Fit with  $63 \pm 5 \mu\text{m-atm}$  of SO<sub>2</sub> (#595)

# Secular evolution of SO<sub>2</sub>

- Strong variability on timescales larger than a week.
- Decrease by a 5 to 10 factor between 2007 and 2012.



- **Decrease very similar to the 1980's**
- $\sim 30$  Earth year periodicity ?
  - Data coverage too sparse and too short to be conclusive.

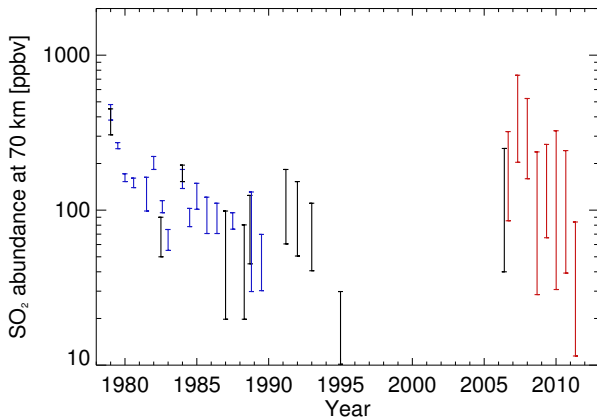
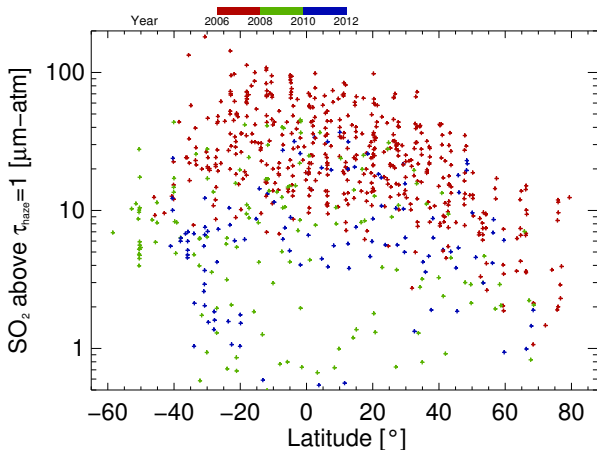


Figure: Secular evolution of SO<sub>2</sub> at cloud top level (UVIS, SPICAV-UV)

# $N_{\text{SO}_2}$ vs. Latitude

## • Evidence for two regimes

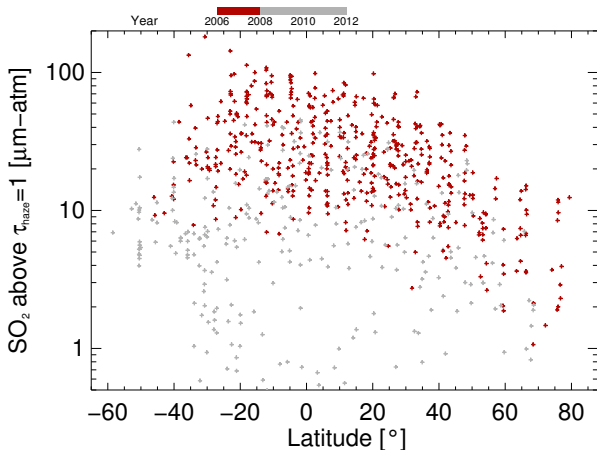
- Most of the time: decreasing  $N_{\text{SO}_2}$  with increasing latitude.
- At some point after 2009: increasing  $N_{\text{SO}_2}$  with increasing latitude.



# $N_{\text{SO}_2}$ vs. Latitude

## • Evidence for two regimes

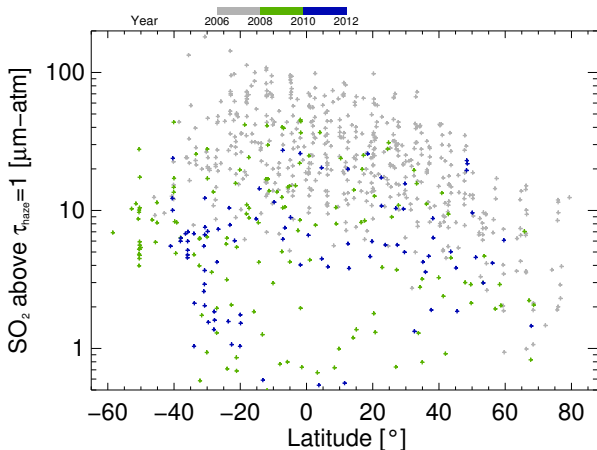
- Most of the time: decreasing  $N_{\text{SO}_2}$  with increasing latitude.
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# $N_{\text{SO}_2}$ vs. Latitude

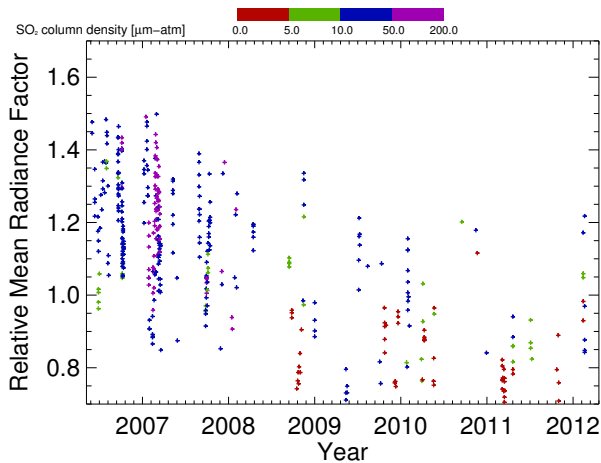
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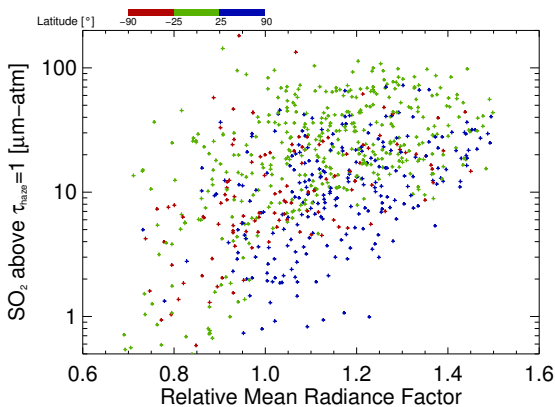
# Secular Evolution of mean UV brightness

- **Substantial decrease ( $\sim -40\%$ ) over 5 years.**
- Concurrent with  $\text{SO}_2$  decrease. Causal link?



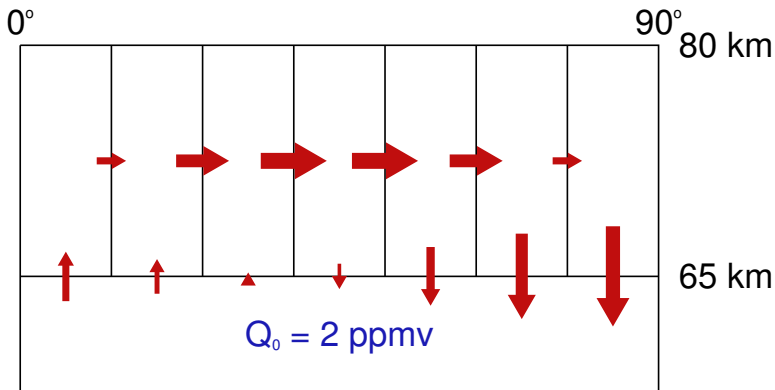
# Correlation between $N_{\text{SO}_2}$ and UV brightness

- **UV absorber anti-correlated with  $\text{SO}_2$  column density in excess of  $10 \mu\text{m-atm}$ .**
  - Hints at a conversion between  $\text{SO}_2$  and UV absorber.
  - **And/Or** a sheltering of  $\text{SO}_2$  by overlying UV bright haze



## • Simple box model

- Prescribed meridional circulation, photochemical time,  $\text{SO}_2$  abundance in the reservoir.
- Able to fairly simulate decreasing  $\text{SO}_2$  with increasing latitude.



- Simple box model

- Prescribed meridional circulation, photochemical time,  $\text{SO}_2$  abundance in the reservoir.
- Able to fairly simulate decreasing  $\text{SO}_2$  with increasing latitude.

Figure: Simulation with  $V_{\text{max}} = 12 \text{ m/s}$ ,  $Q_{65 \text{ km}} = 2 \text{ ppm}$  and  $\tau_0 = 5 \cdot 10^4 \text{ s}$  starting from no  $\text{SO}_2$  above the clouds

- Simple box model

- Also able to reproduce (qualitatively) rapid  $\text{SO}_2$  decrease along with a suppression of the latitudinal gradient

Figure: Simulation with  $V_{\text{max}} = 0 \text{ m/s}$ ,  $Q_{65 \text{ km}} = 2 \text{ ppm}$  and  $\tau_0 = 5 \cdot 10^4 \text{ s}$  starting from previous equilibrium

- Long-term

- **SO<sub>2</sub> at Venus cloud top alternates between rapid increases (seen in early 2007 ?) and slower decreases (lasting at least 5 – 10 years).**
- Evidence for **anti-correlated variations of UV brightness.**

- Short-term

- **Evidence for two regimes** for SO<sub>2</sub>, fast transitions between regimes (several Earth days).

**SO<sub>2</sub>-rich** Advection of volatiles more efficient than photo-chemical removal. Usual situation between 2006 and 2008.

**SO<sub>2</sub>-poor** Occurs mainly after 2008. Probably caused by a temporary decreases in the general circulation and/or SO<sub>2</sub> mixing ratio within and below the clouds.

- Changes in the prevalence of both regimes may also cause the long-term (decadal) variations.

- Manuscript being reviewed at *Nature Geoscience*.

- **How does upper haze variability affect SO<sub>2</sub> retrievals?** VMC and/or VIRTIS-Vis could help.
  - Retrieving UV cloud top height is possible with SPICAV (CO<sub>2</sub> band near 200 nm), but with a low accuracy ( $76 \pm 6$  km). No variations found.
- **Challenge to chemical models:** simulating these two regimes.
- **Extend SPICAV data set**, but most usable orbits have been processed between 2006 and 2012...
  - New observation modes ? (mapping)
- **Need for a long-term monitoring of SO<sub>2</sub>** (for at least 30 years!)
  - Measurements of other minor species involved in sulphur chemistry also highly welcome (CO, H<sub>2</sub>O, HDO).

SO<sub>2</sub>/CO<sub>2</sub> maps near 7.4 μm  
from Encrenaz et al. (2012)  
for 10-11-12 Jan. 2012