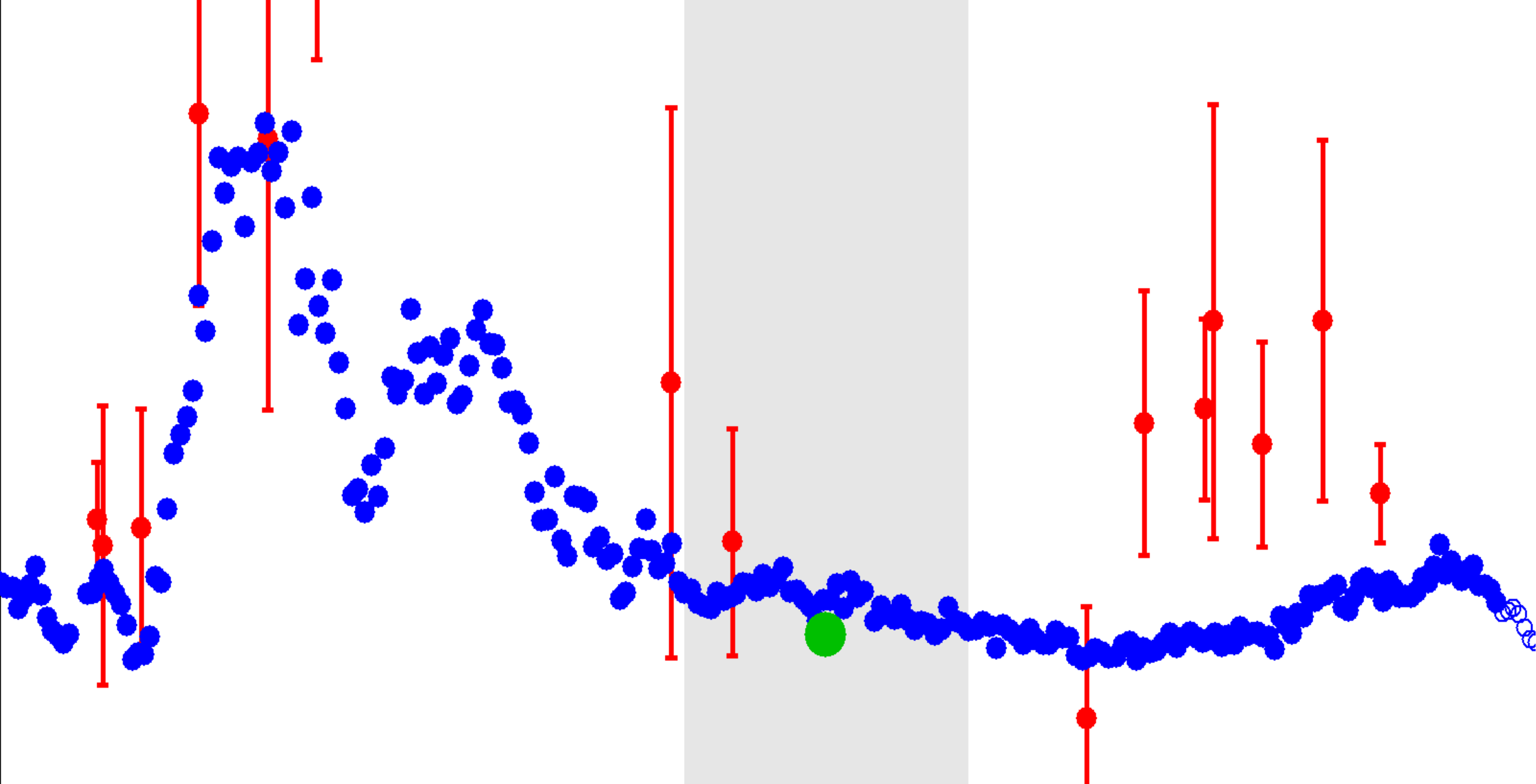
DISCOVER – AQ

September 5 – 7 2010

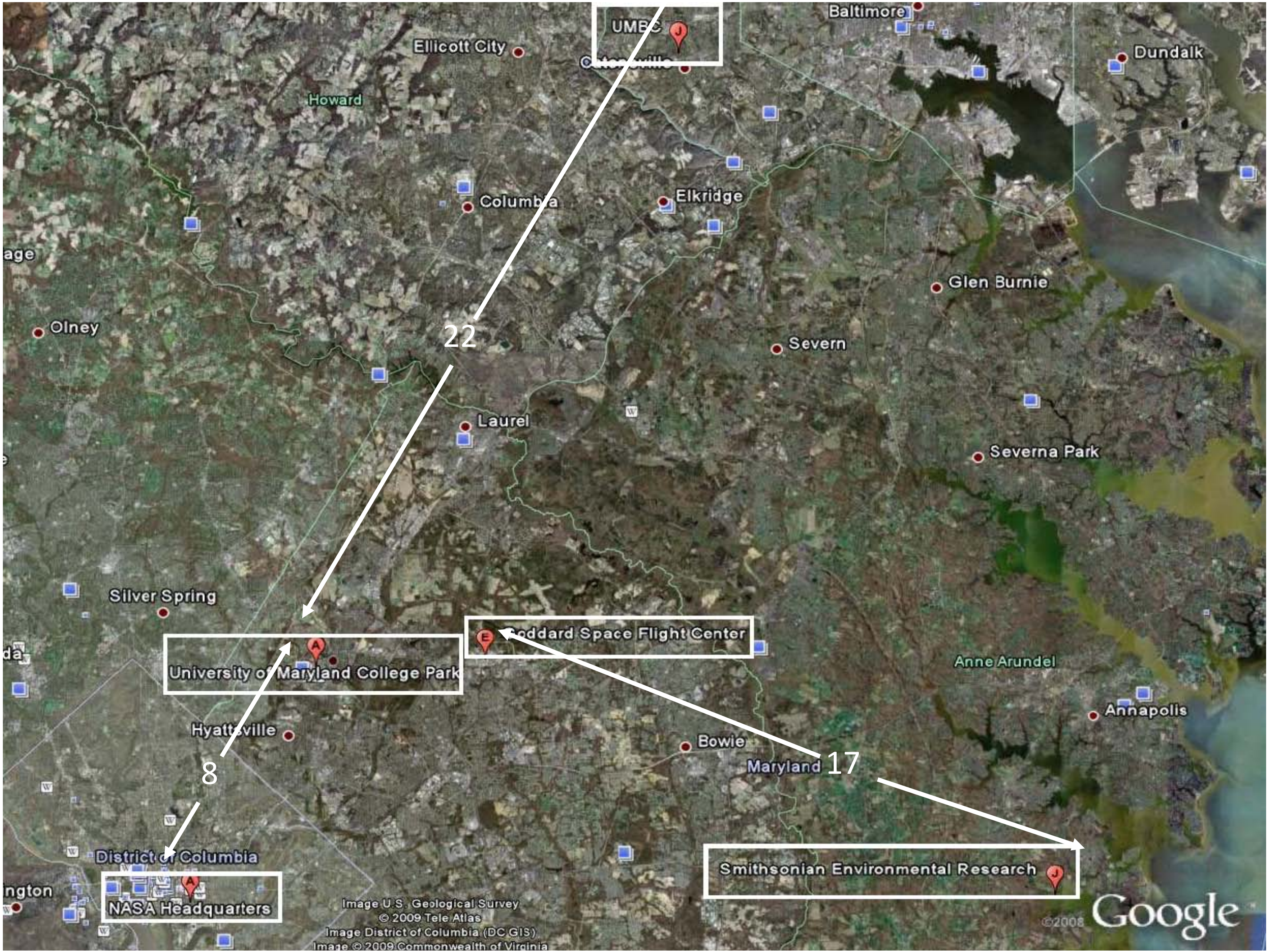
The PANDORA Small Spectrometer System

J. Herman, A. Cede, N. Abuhassan, Maria Tzortziou

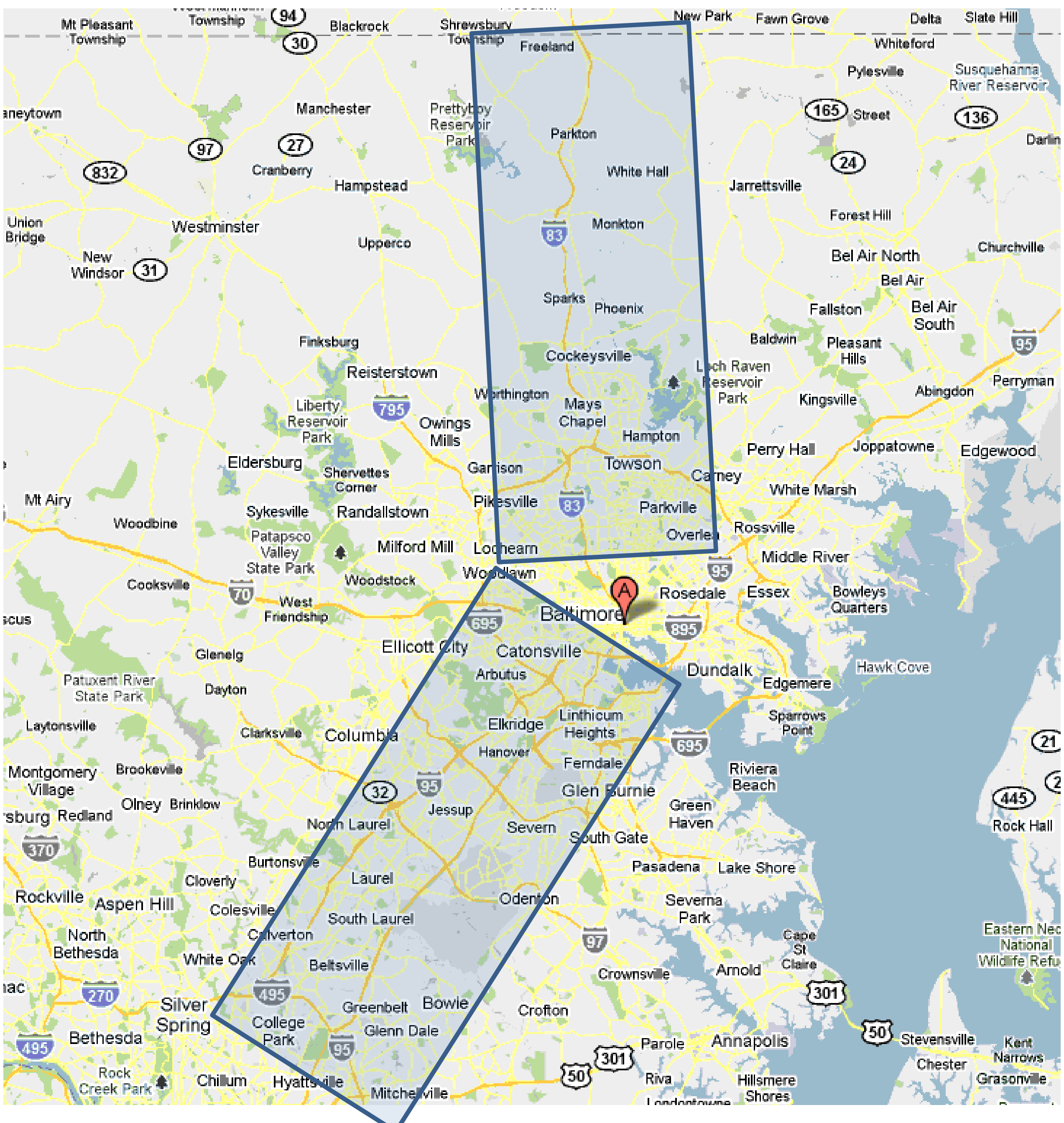
University of MD



DISCOVER-AQ INITIAL SITES



DISCOVER-AQ INITIAL SITES



What is PANDORA?

Pandora is a small spectrometer system, which we have been developing since 2006. It consists of …

a “miniature” spectrometer

and a head sensor on a sun tracker

Measures sun and sky radiance from 270 to 530 nm in 0.5 nm steps with a 1.6° field of view. Products: NO_2, H_2O, O_3, SO_2, HCHO, and aerosol properties with 1% accuracy and 0.1% precision.

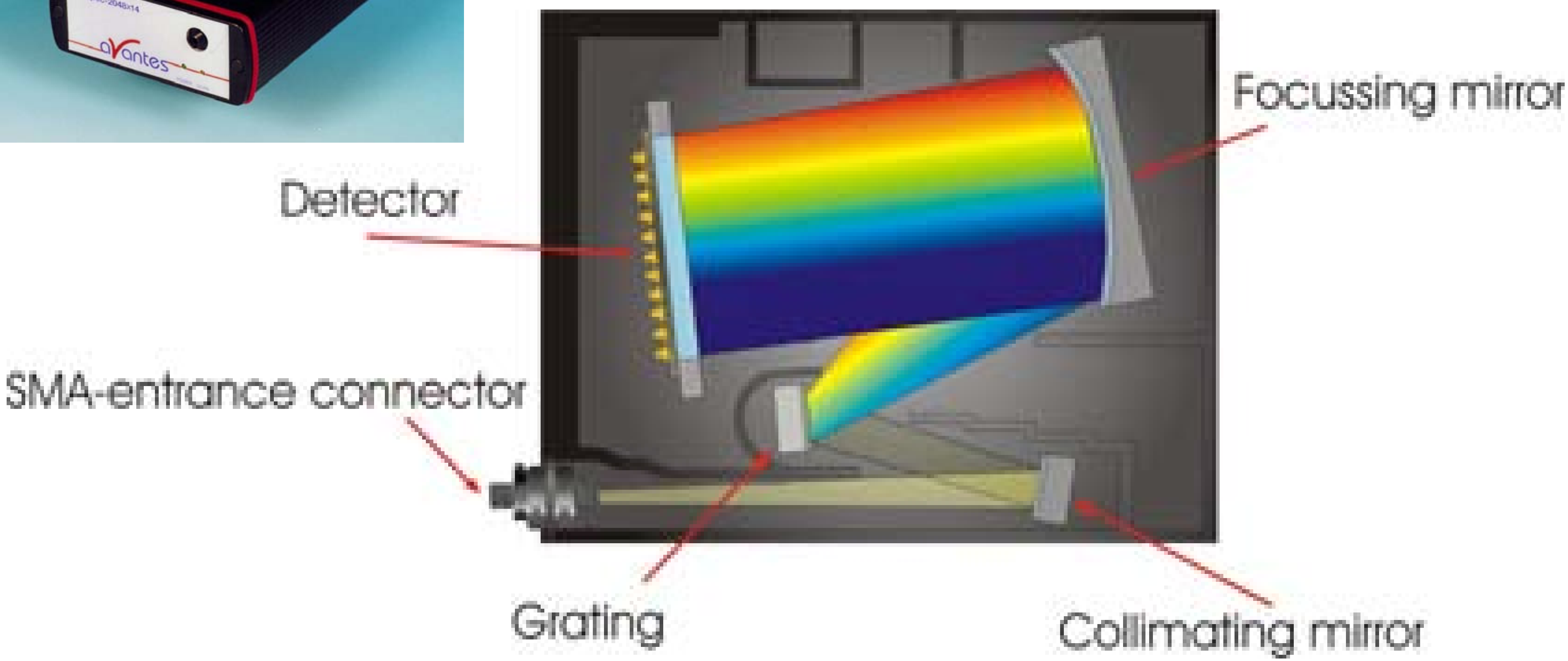
PANDORA Specifications

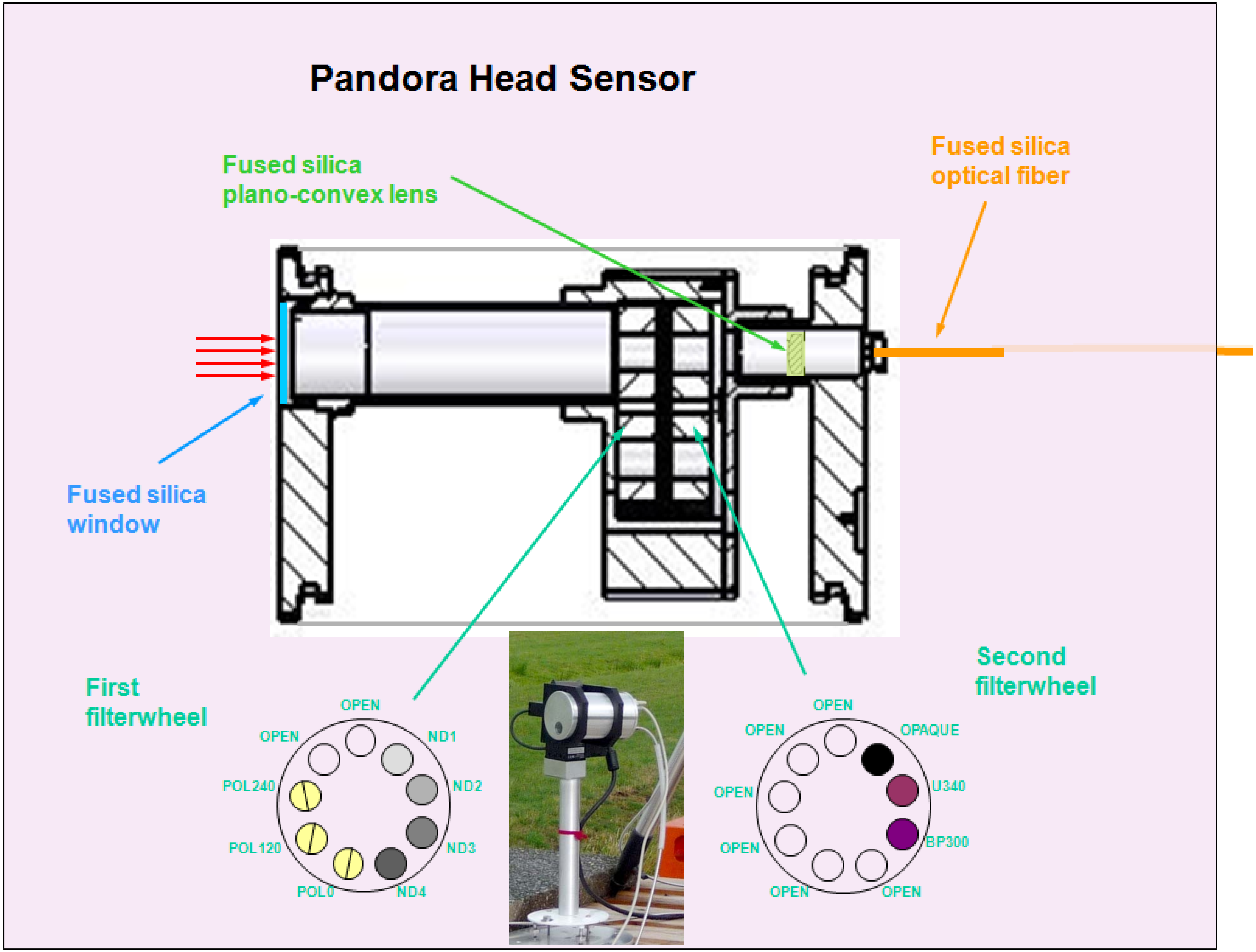
- **Sun and sky spectrometer, 75mm focal length symmetrical Czerny-Turner**
- **Uses Hamamatsu image sensor (CCD or CMOS linear array)**
- **Wavelength range: 270nm to 530nm, resolution ~0.5nm**
- **Field of view ~1.8 full angle**
- **Two filterwheels with opaque for dark count, short-pass filters to reduce stray light and attenuation filters to adjust throughput**
- **S/N: ~400:1 for single shot at 400nm**
  → >10,000 for 20sec average
- **Regular measurement mode:**
  Every 2min one 20sec measurement with each filter + dark counts

• **New version has 10,000:1 in 7 seconds**

Head Sensor

Avantes – symmetrical Czerny-Turner

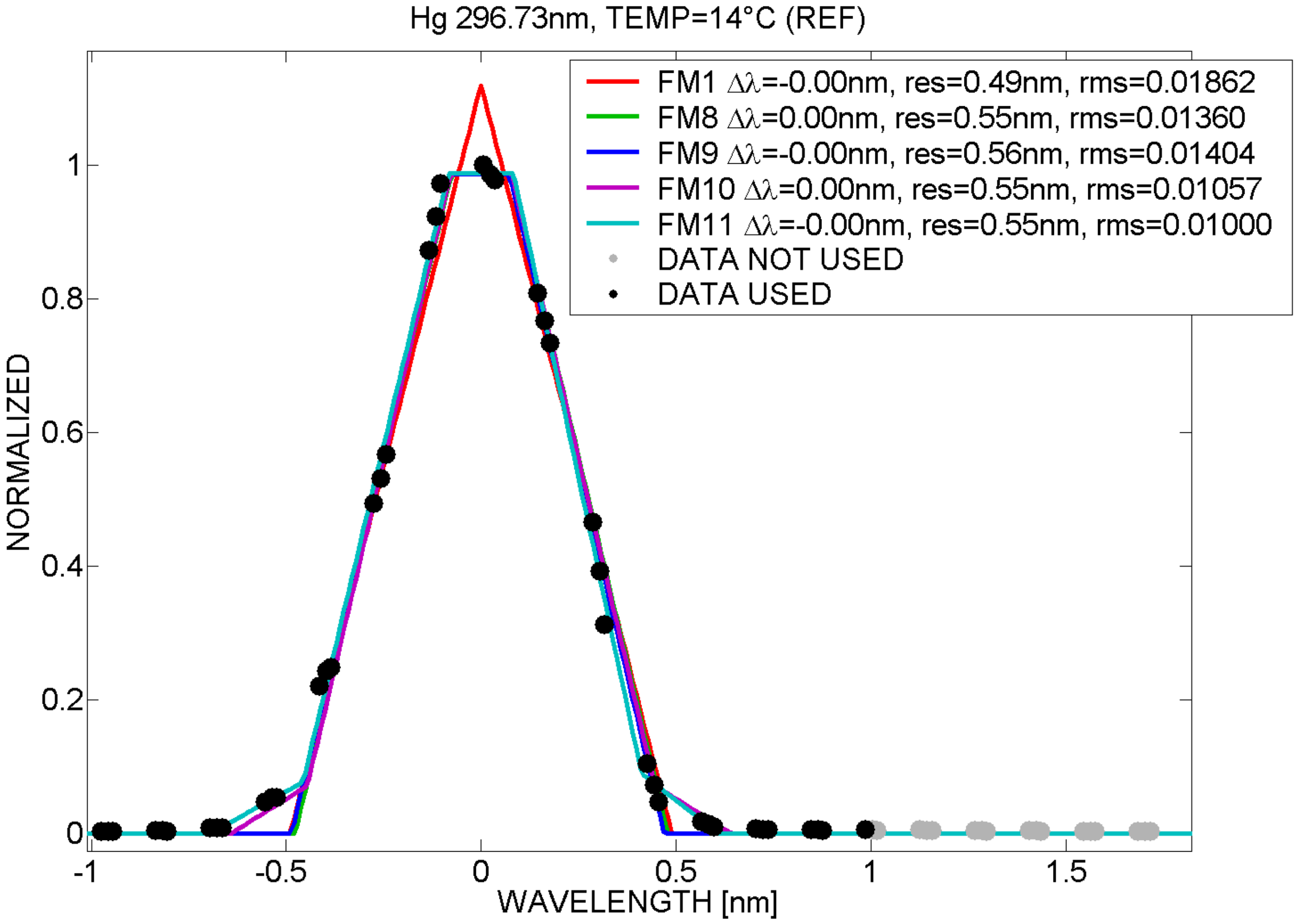



Pandora Head Sensor
Fused silica
plano-convex lens
Fused silica
optical fiber
Fused silica
window
First
filterwheel
OPEN
OPEN
ND1
POL240
ND2
POL120
ND3
POL0
ND4
Second
filterwheel
OPEN
OPEN
OPAQUE
OPEN
U340
OPEN
BP300
OPEN
OPEN

Key to PANDORA's Success

Slit function characterization

Avantes has very small wavelength shift with temperature (3pm/°C)



20 kg PANDORA TRAVELS EASILY

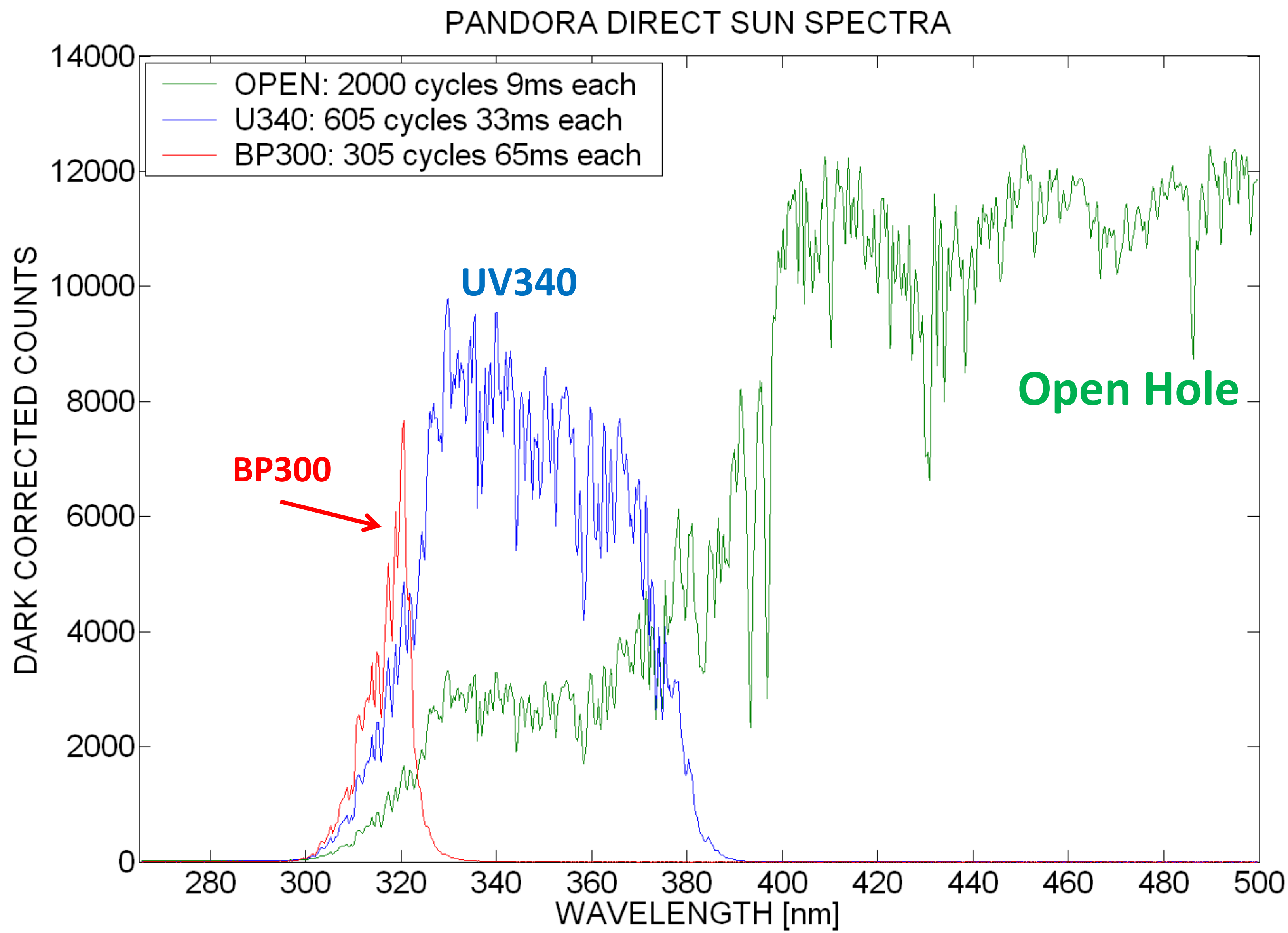
Carry-ON
+
Checked baggage

What Does Pandora Measure?

PANDORA makes direct-sun spectrum using the filter wheel
CCD Two Filter wheels, one with ND filters
CMOS One Filter wheel

1. **Open hole (green)**
2. **U340 bandpass filter (blue)**
3. **BP300 bandpass filter (red).**

What Does Pandora Measure



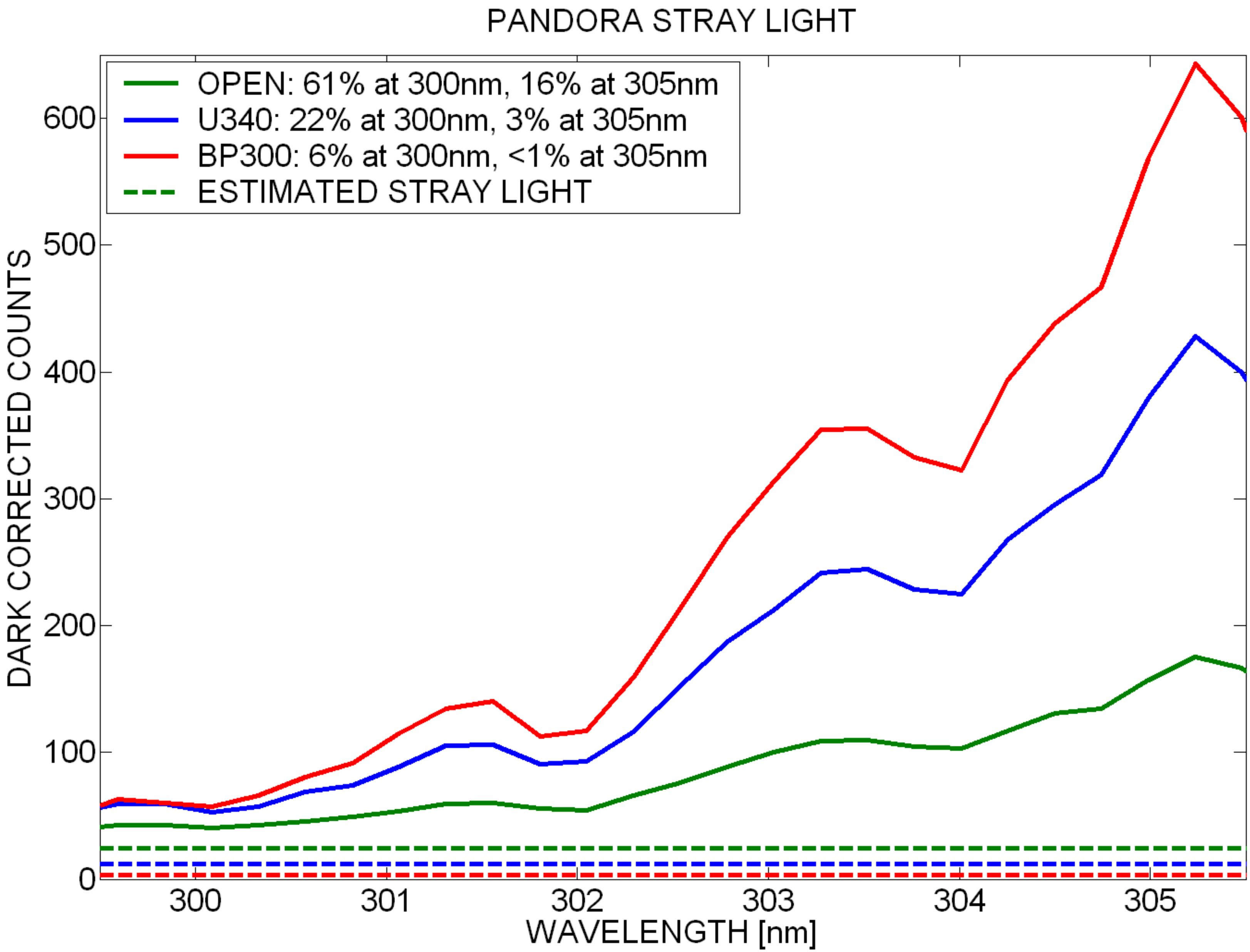
Stray Light

To make successful measurements of atmospheric constituents, stray light must be corrected. This is especially true for ozone at short wavelengths

The estimated ratio R of stray light over the true signal is

Open hole:	**R(300 nm) = 61%**	**R(305) = 16%**
UV340:	**R(300 nm) = 22%**	**R(305) = 3%**
BP300:	**R(300 nm) = 6%**	**R(305) = 1%**

Stray Light



PANDORA STRAY LIGHT
OPEN: 61% at 300nm, 16% at 305nm
U340: 22% at 300nm, 3% at 305nm
BP300: 6% at 300nm, <1% at 305nm
ESTIMATED STRAY LIGHT
DARK CORRECTED COUNTS
0
100
200
300
400
500
600
300
301
302
303
304
305
WAVELENGTH [nm]

Pandora measures radiance with a narrow field of view (~1.6° full angle)

pointing at the sun, the moon, or the sky

Pandora measures radiance with a narrow field of view (~1.6° full angle)

pointing at the sun, the moon, or the sky

Currently we use a wavelength range of 270-530nm and a resolution of ~0.5nm (similar to OMI)

Pandora measures radiance with a narrow field of view (~1.6° full angle)

pointing at the sun, the moon, or the sky

Currently we use a wavelength range of 270-530nm and a resolution of ~0.5nm (similar to OMI)

From the measured spectra we obtain column amounts of

O_3	305 – 330 nm and 440 – 500 nm
NO_2	370 – 500 nm
SO_2	305 – 330 nm
H_2O	500 – 515 nm (442 and 507 nm)
HCHO	330 – 370 nm
O_2O_2	330 – 500 nm (340, 360, 380,440 nm)
BrO	330 – 370 nm
AOT	330 – 500 nm

Additional aerosol information (Absorption & Particle Size)

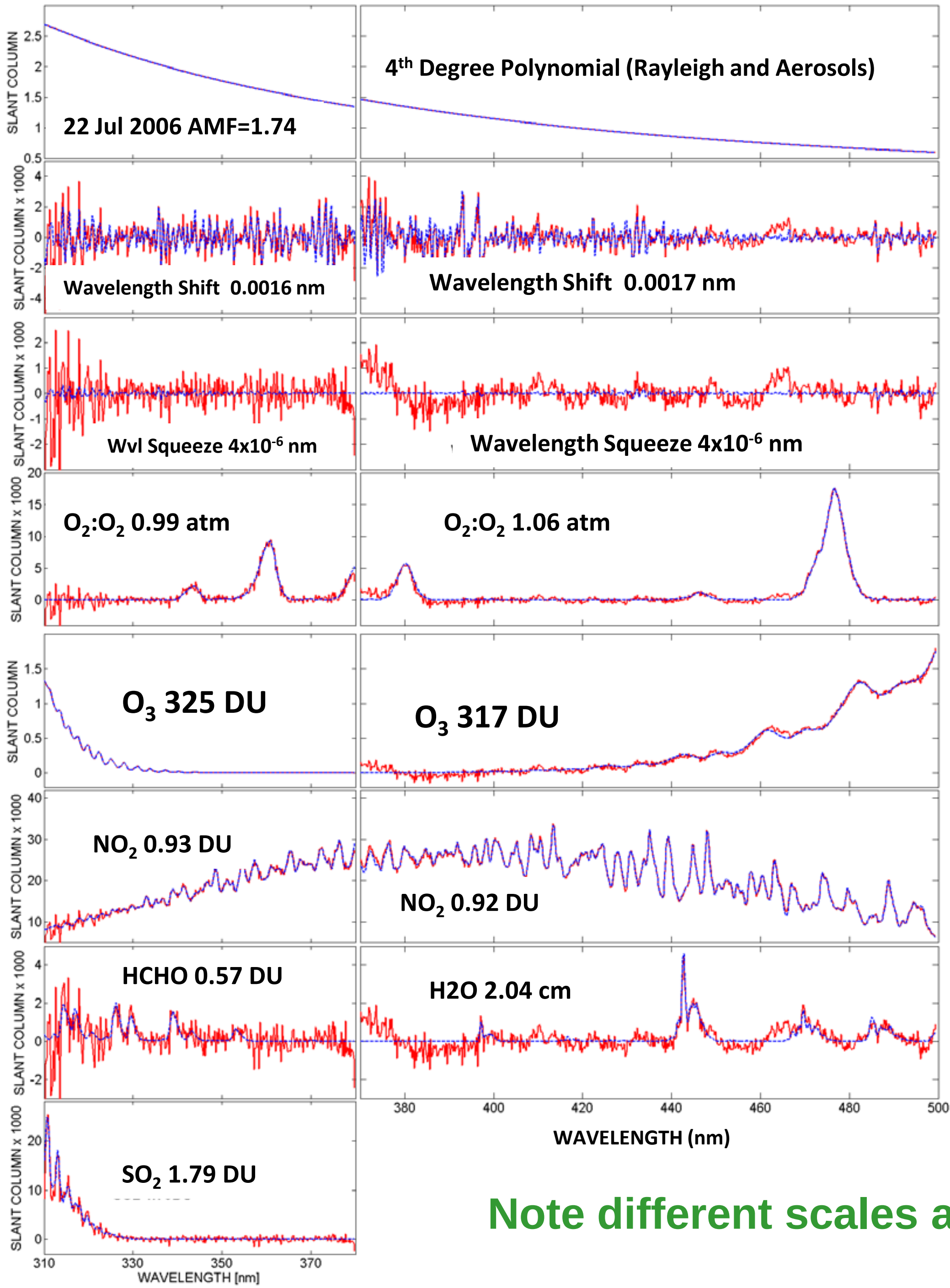
Pandora measures radiance with a narrow field of view (~1.6° full angle) pointing at the sun, the moon, or the sky

Currently we use a wavelength range of 270-530nm and a resolution of ~0.5nm (similar to OMI)

From the measured spectra we obtain column amounts and profiles of

O_3	and O_3 Profiles	Direct Sun	Sky Measurement
NO_2	and NO_2 Profiles	Direct Sun	Sky Measurement
SO_2		Direct Sun	
H_2O		Direct Sun	
HCHO		Direct Sun	
O_2O_2		Direct Sun	
BrO		Direct Sun	
AOT		Direct Sun	
Additional aerosol information (Absorption & Particle Size)		Sky Measurement	

Spectral fitting



Left (310-375 nm) **Right** (375-500)

Measurement (**red**), Spectral fit (**blue**)

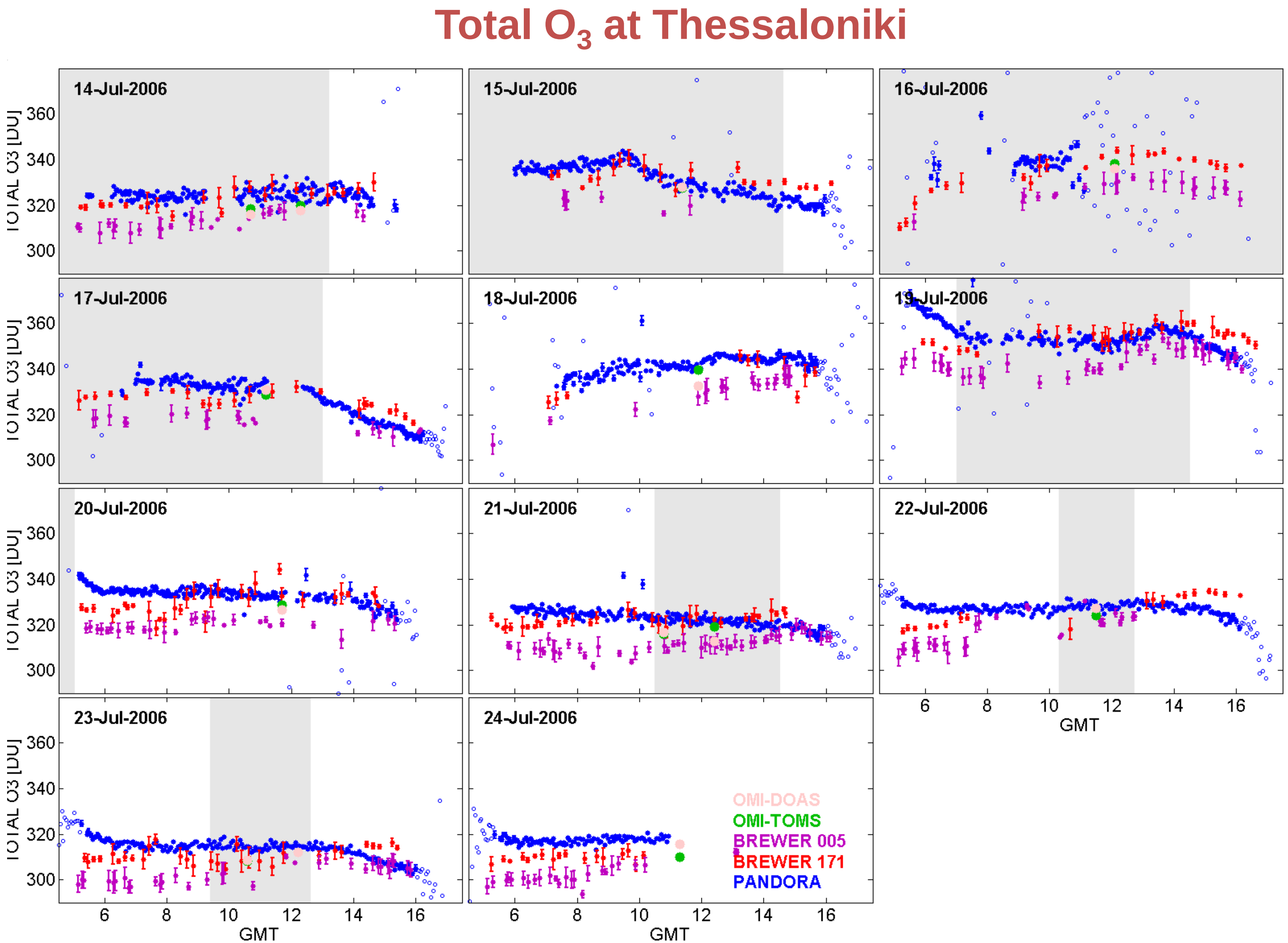
Left side: Fit with a 4th order polynomial, wavelength shift and squeeze, and absorptions of O_2:O_2, O_3, NO_2, HCHO, and SO_2 in the 310-380nm window, fitting rms=0.085%

Right side: fit with a 4th order polynomial, wavelength shift and squeeze, and absorptions of O_2O_2, O_3, NO_2, and H_2O in the 370-500nm window, fitting rms=0.058%

Data in figure legends give the retrieved vertical columns

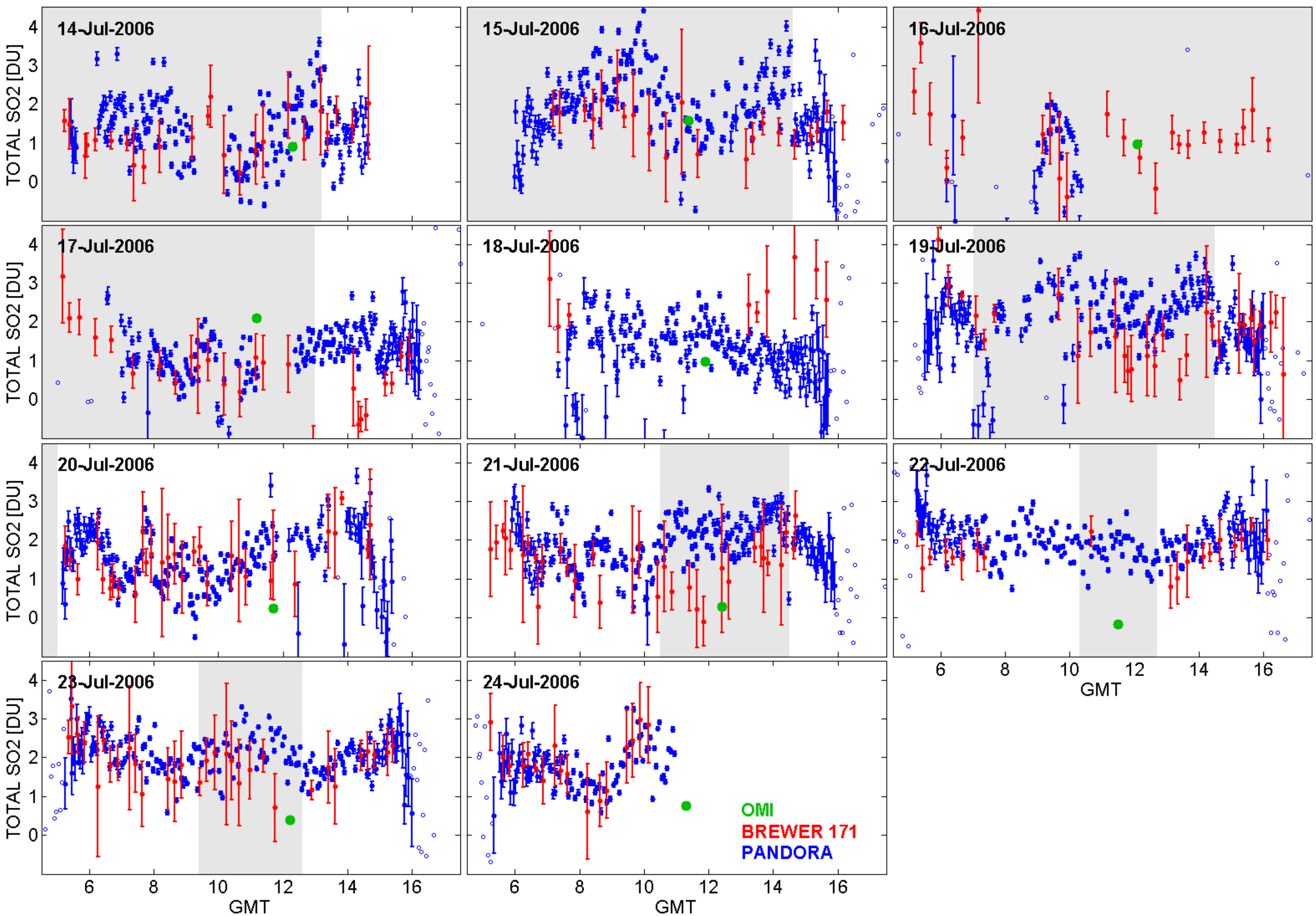
Note different scales at y-axis!

What is the amount and temporal variability of O3?



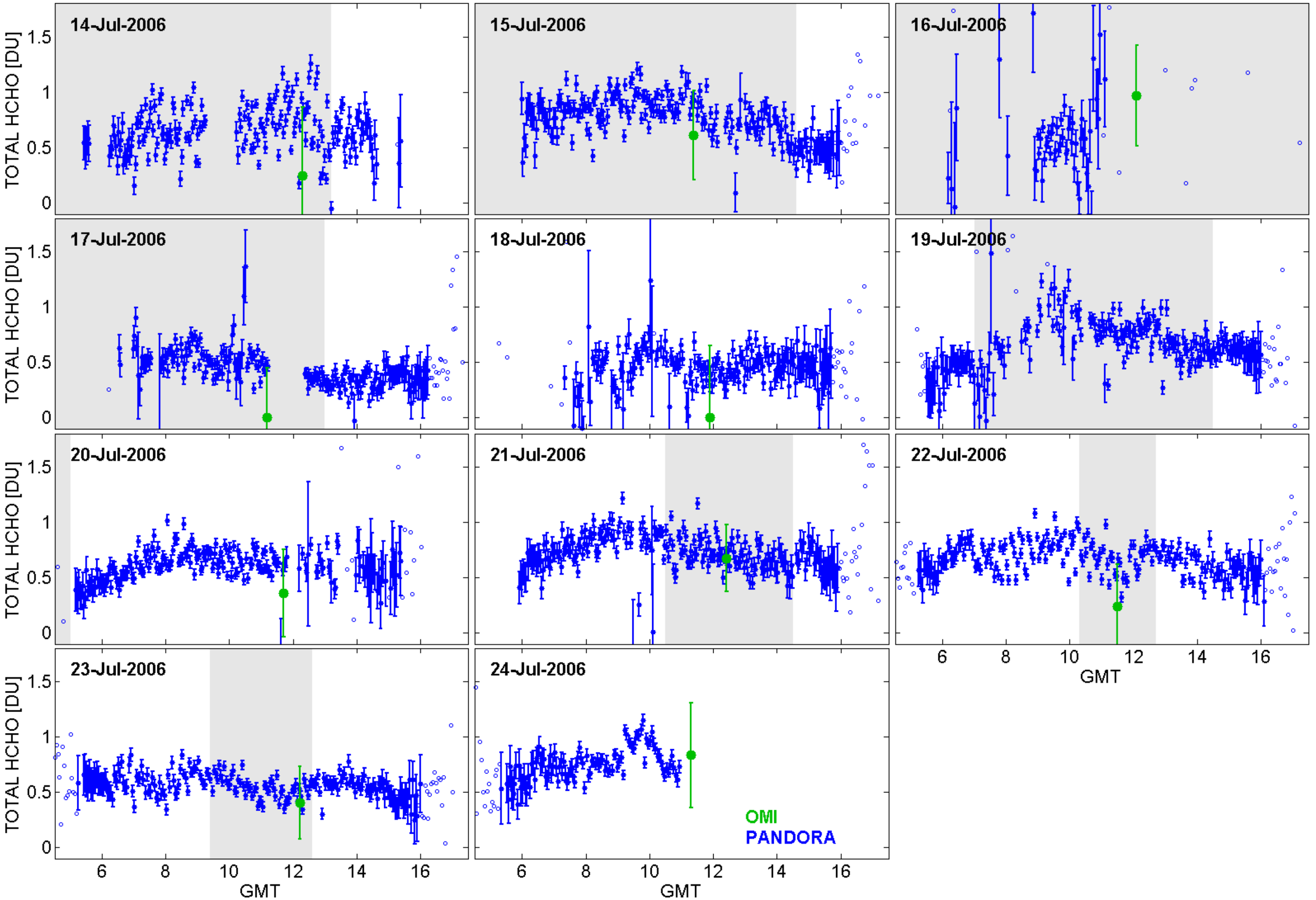
What is the amount and temporal variability of SO_2?

Total SO_2 at Thessaloniki



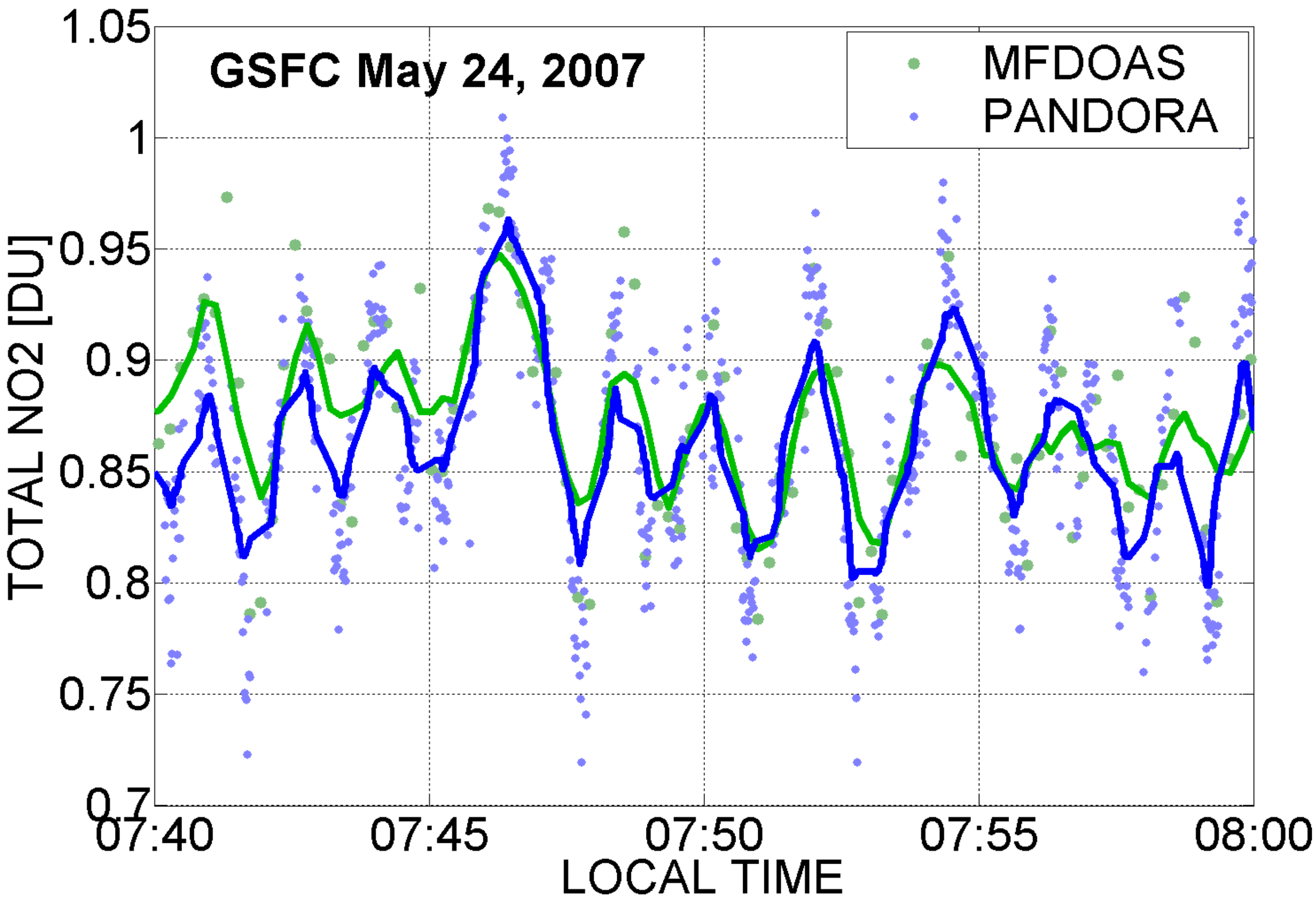
What is the amount and temporal variability of HCHO?

Total HCHO at Thessaloniki



Can You See NO_2 in the air?
NO_2 is mostly in a Thin Layer

Minute –by Minute Temporal variation of NO_2 at GSFC



Dots: PANDORA (2s sampling) and MFDOAS (4s sampling)

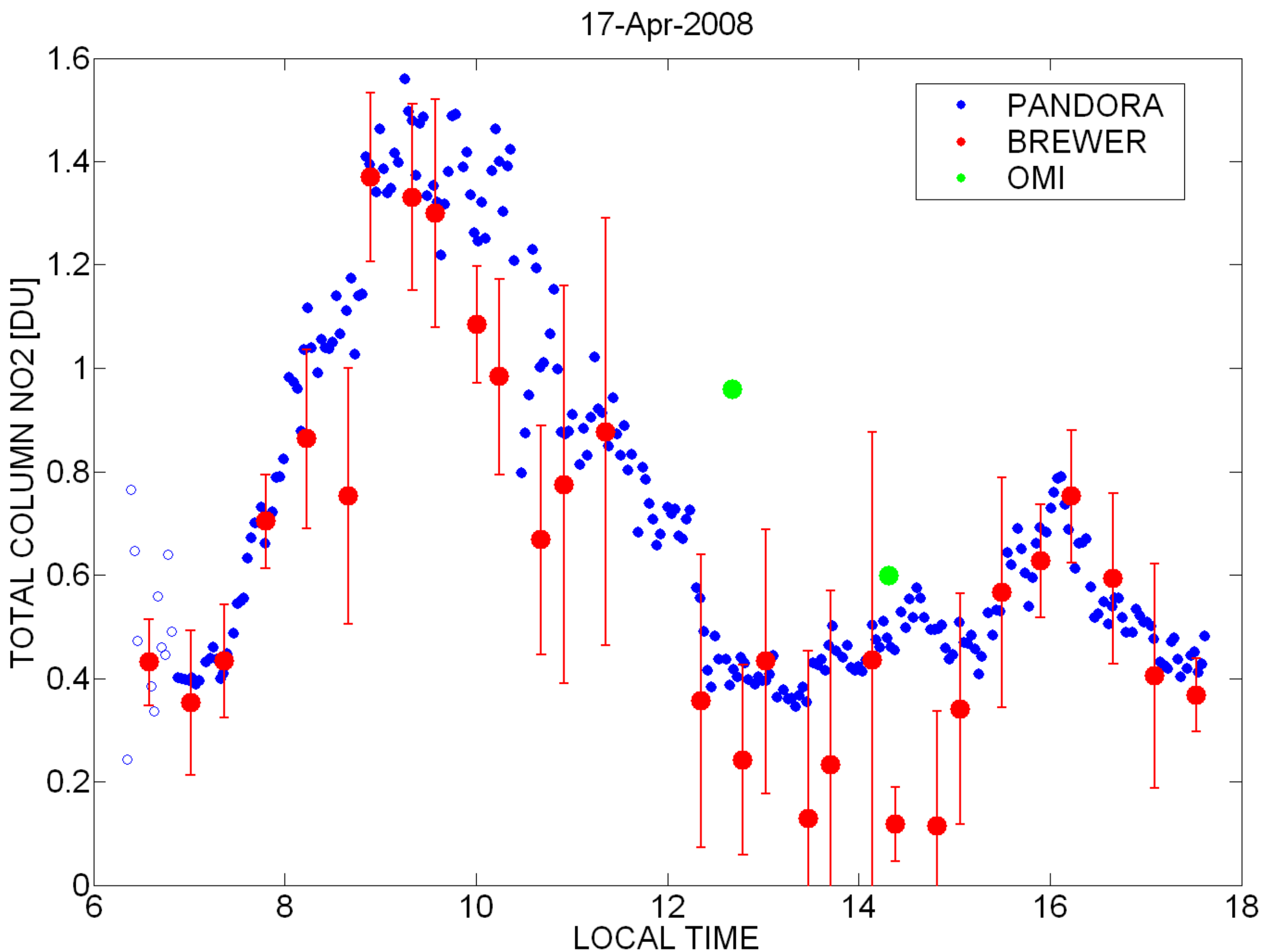
Lines: Running 1min averages

Changing rate for the total NO_2 column of 0.1DU/min (=total stratosphere!)

Data even look like a cycle with a 2min period.

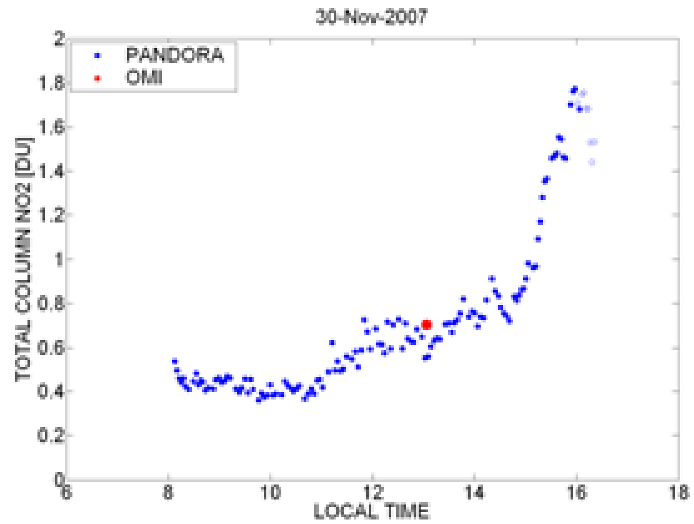
What is the amount and temporal variability of NO_2?

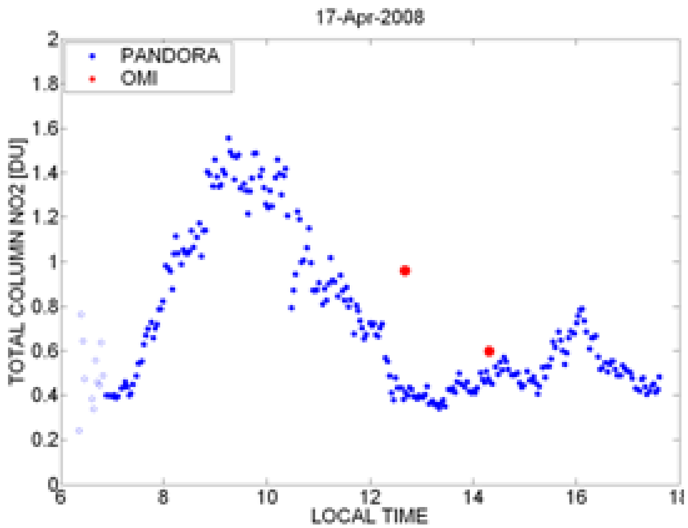
Total NO_2 at GSFC

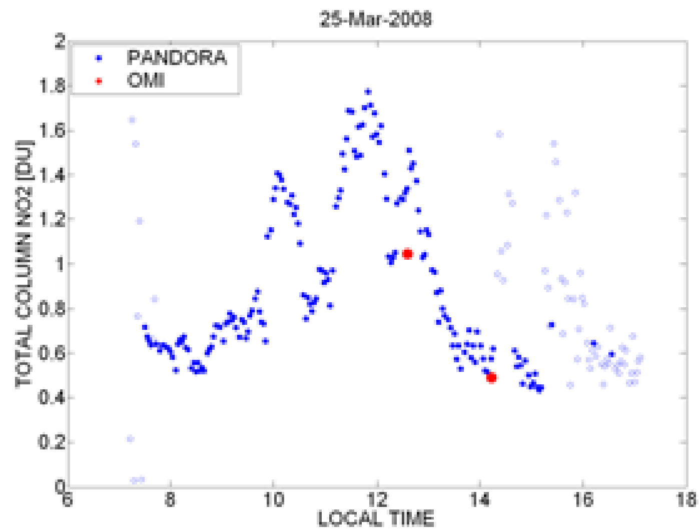


How Does NO_2 vary day to day?

3 examples of the diurnal variation of the total NO_2 column at Goddard Space Flight Center measured with PANDORA-1; days with large NO_2 amounts were picked; OMI data are red and PANDORA data are solid blue for cloud screened data and open blue for cloud-affected data

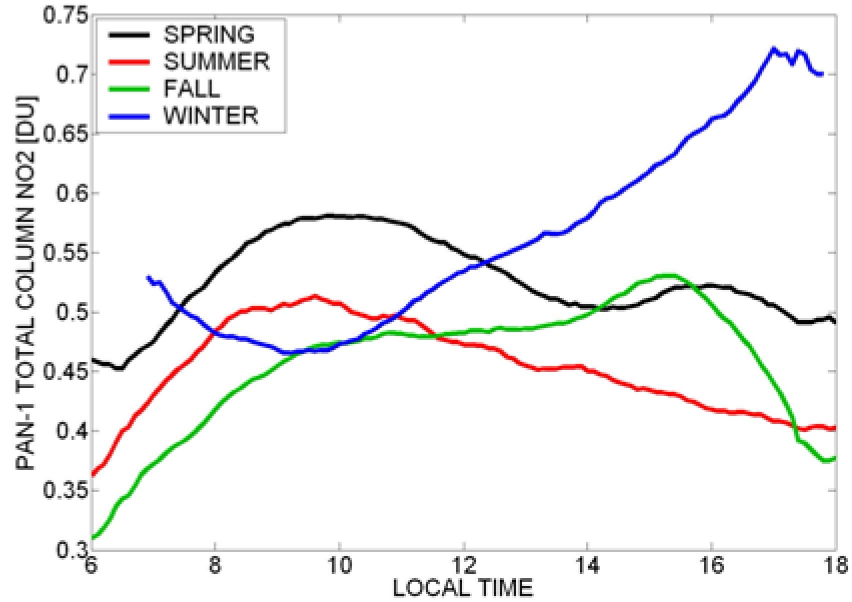




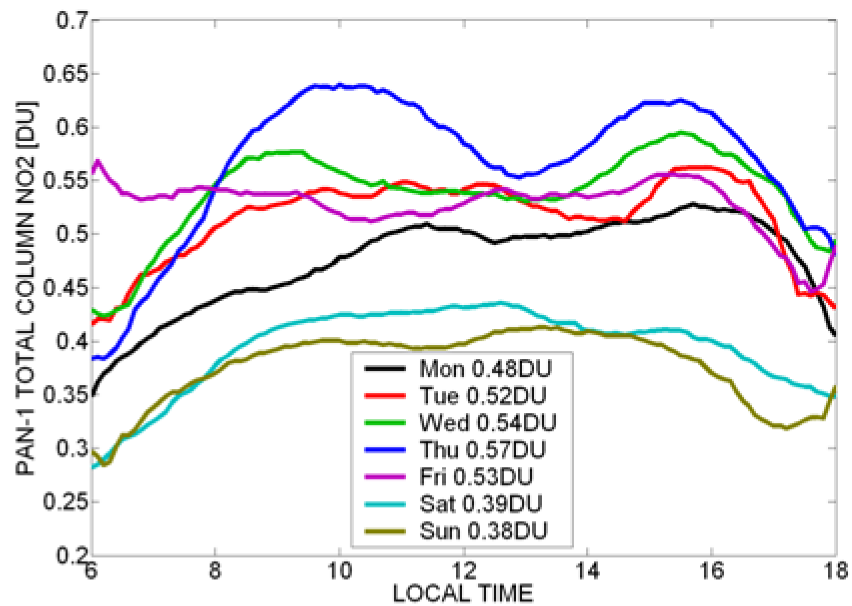


Running 2-hour mean of total NO_2 columns measured at Goddard Space Flight Center for the four seasons (top) and for the days of the week (bottom); data base is from 2006-12-18 to 2008-10-15

Or Seasonally



Or by day of the week



→ We would like PANDORA to help answer these questions:

What is the amount and temporal variability of these atmospheric constituents?

→ We would like PANDORA to help answer these questions:

What is the amount and temporal variability of these atmospheric constituents?

How can we compare with and improve satellite and aircraft measurements?

→ We would like PANDORA to help answer these questions:

What is the amount and temporal variability of these atmospheric constituents?

How can we compare with and improve satellite and aircraft measurements?

Can a network of Pandoras be used to improve regional models and how many are needed. <u>DISCOVER-AQ will have 12 PANDORAS</u>

→ We would like PANDORA to help answer these questions:

What is the amount and temporal variability of these atmospheric constituents?

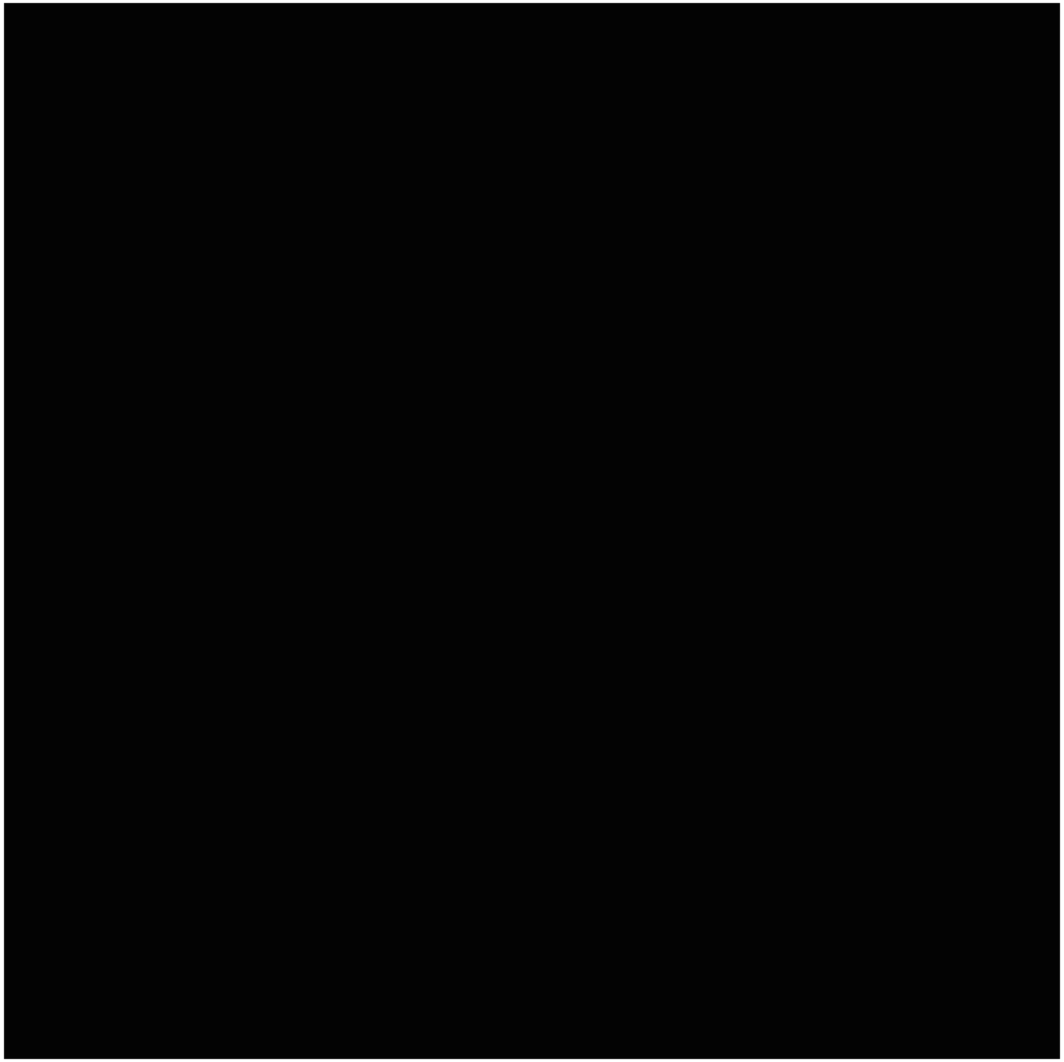
How can we compare with and improve satellite and aircraft measurements?

Can a network of Pandoras be used to improve regional models and how many are needed. DISCOVER-AQ will have 12 PANDORAS

How can the different remote sensing techniques be compared?

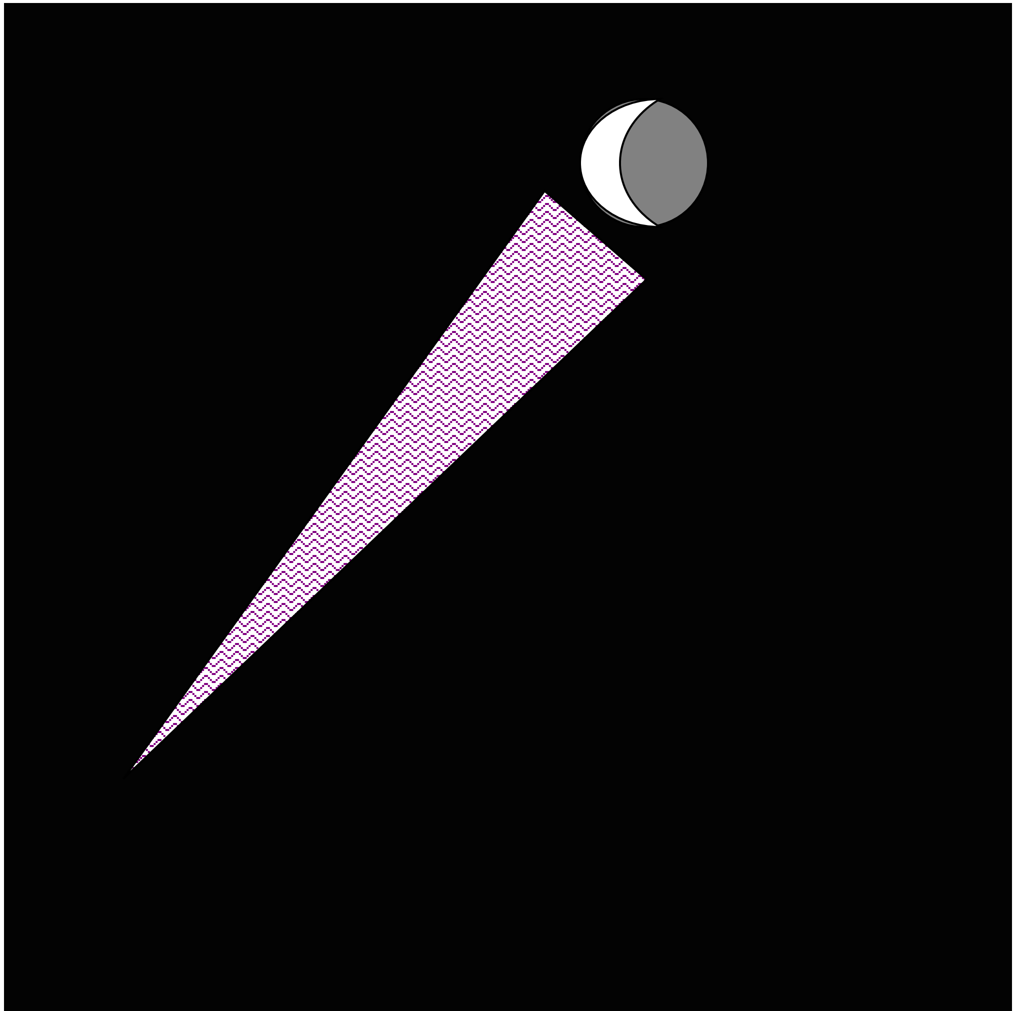
What is happening at night based on lunar measurements that will help regional models become more accurate?

For Regional Models,
What is happening to NO_2 at night?



What is happening to NO_2 at night?

→ **Pandora (CCD) can measure NO_2 using the direct moon, since the lunar brightness is a little greater than the blue daytime sky**



Conclusions 1

→ PANDORA is a low cost, easy to transport measurement system capable of making accurate trace-gas measurements with high time resolution (<1min). It can be used to monitor air pollution and to validate satellite data, aircraft data, and improve chemistry-transport models.

→ The ground-based measurements have been compared to OMI retrievals at a remote, a suburban, and an urban site. The agreement is in general very good. Nearly all situations with large differences between ground and satellite data can be explained by the different viewing geometry.

→ OMI's relatively small footprint is capable of picking up regional plumes with enhanced NO_2, but what about local scale plumes? Here we need aircraft data.

→The spatial variability of NO_2 at a scale smaller than one OMI pixel is still unknown. The temporal variability of NO_2 at a polluted site like Goddard Space Flight Center suggests that the spatial variability must also be very large.

→The 12 DISCOVER-AQ Pandoras combined with models will answer these questions

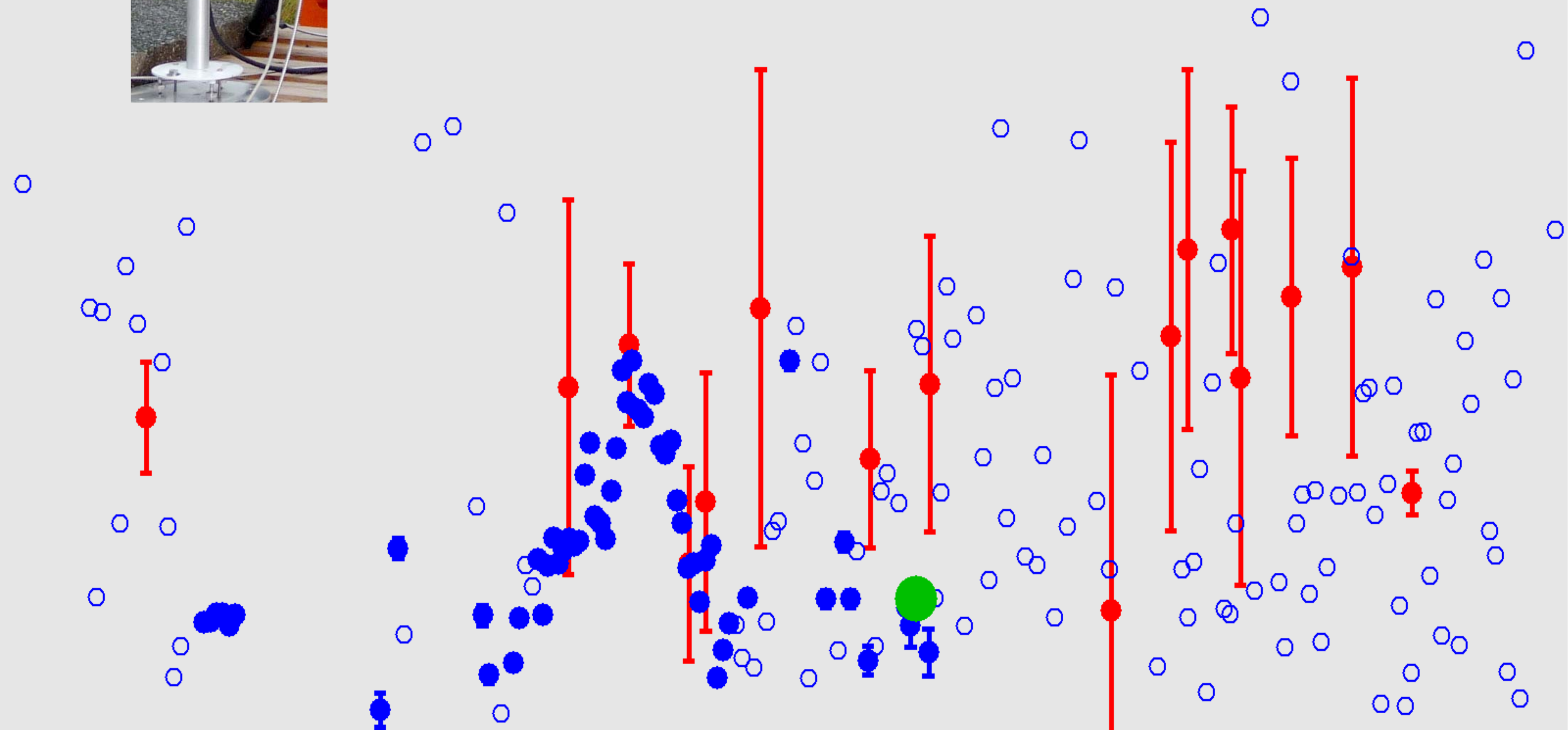
Conclusions 2

→ Weekly or monthly measurement campaigns with ground-instruments at one single location do not necessarily provide enough information to validate satellite products like NO_2. Even at rural, unpolluted sites the statistics are too small to draw any conclusion. Monitoring records of 1 year or more are needed at some sites, and short-term records at multiple sites plus aircraft overflights.

→ When measuring at one single ground-location in a polluted area, it might never be possible to separate between the influence of the different viewing geometries and any other potential error sources. Deployment of multiple instruments within a region can solve this problem.

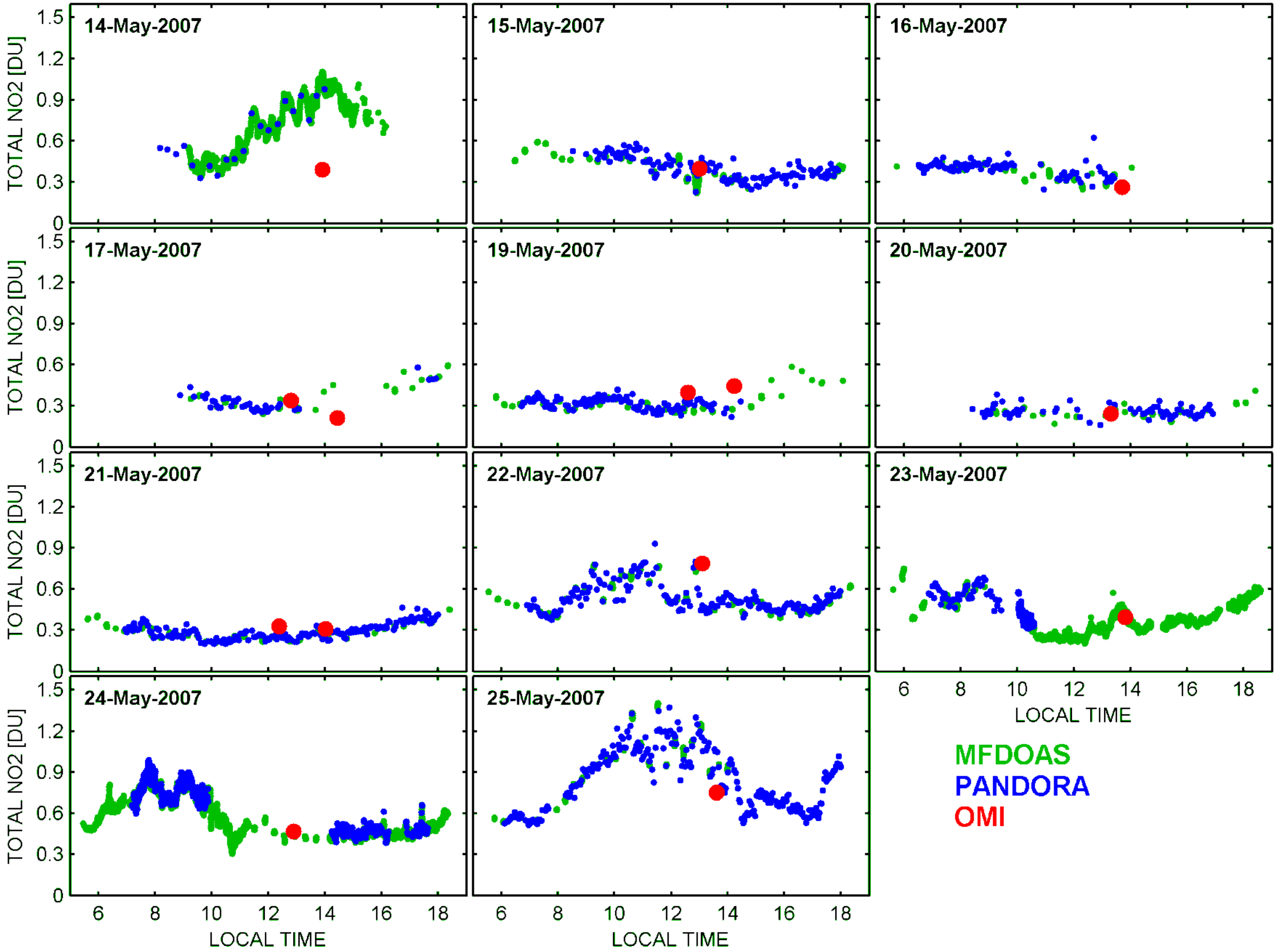
→ The choice of proper ground locations for DISCOVER-AQ is very important. The "perfect" place would be flat with homogeneous surface albedo, and not directly near the sources of tropospheric NO_2 (power plant or heavy traffic). It should not be too remote, since there is no NO_2 variability. A location in the center of a rural area with >100km West-East and >20km North-South extension, with a large city nearby (e.g. ~50km North or South of the location) seems to be an ideal case. There should be enough NO_2 variability, with the plumes having regional scale, which can be compared to models.

Thank you



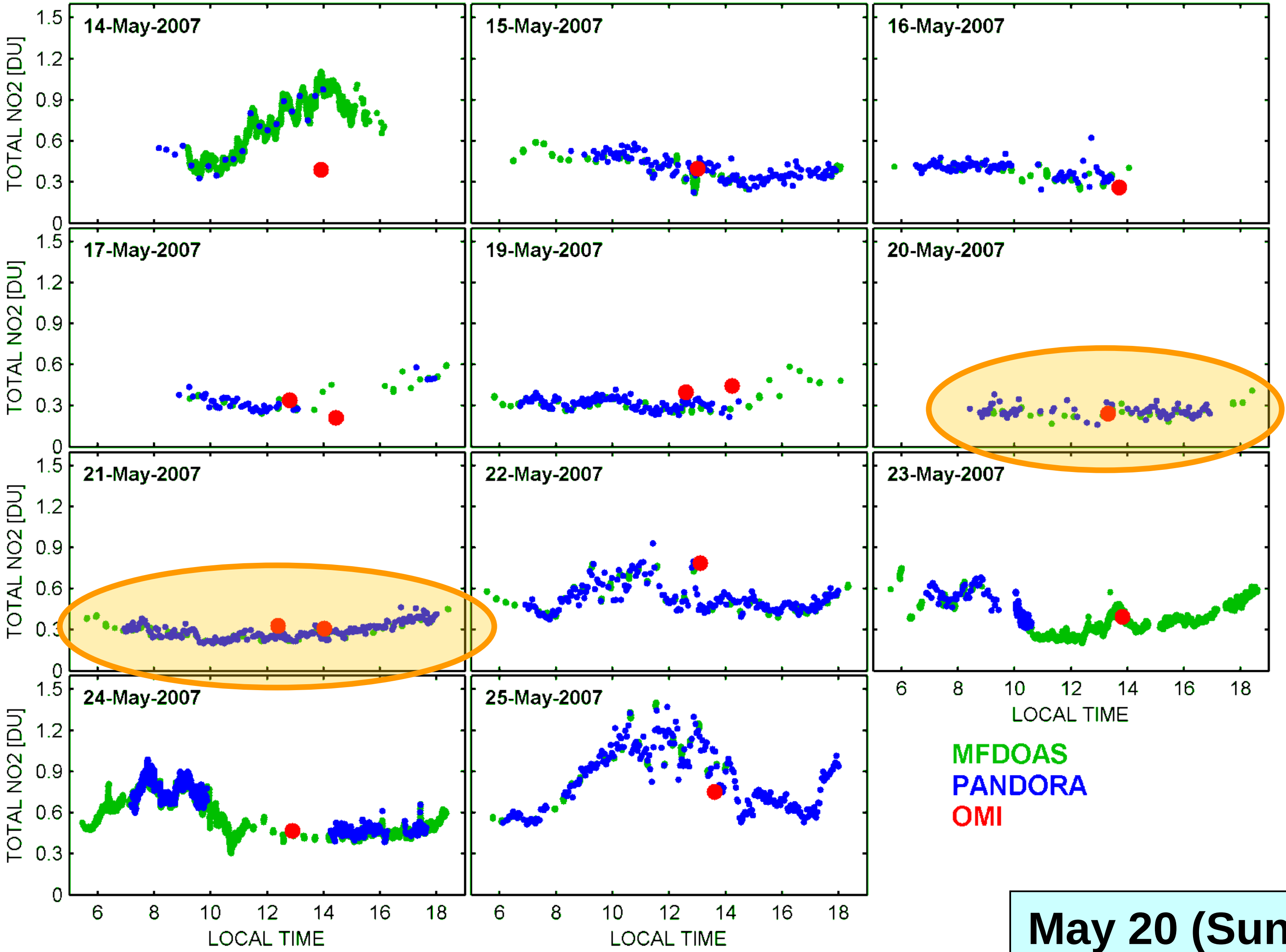
EXTRA SLIDES

Goddard Space Flight Center, MD, USA, 38.99 N, 76.84 W, May 2007



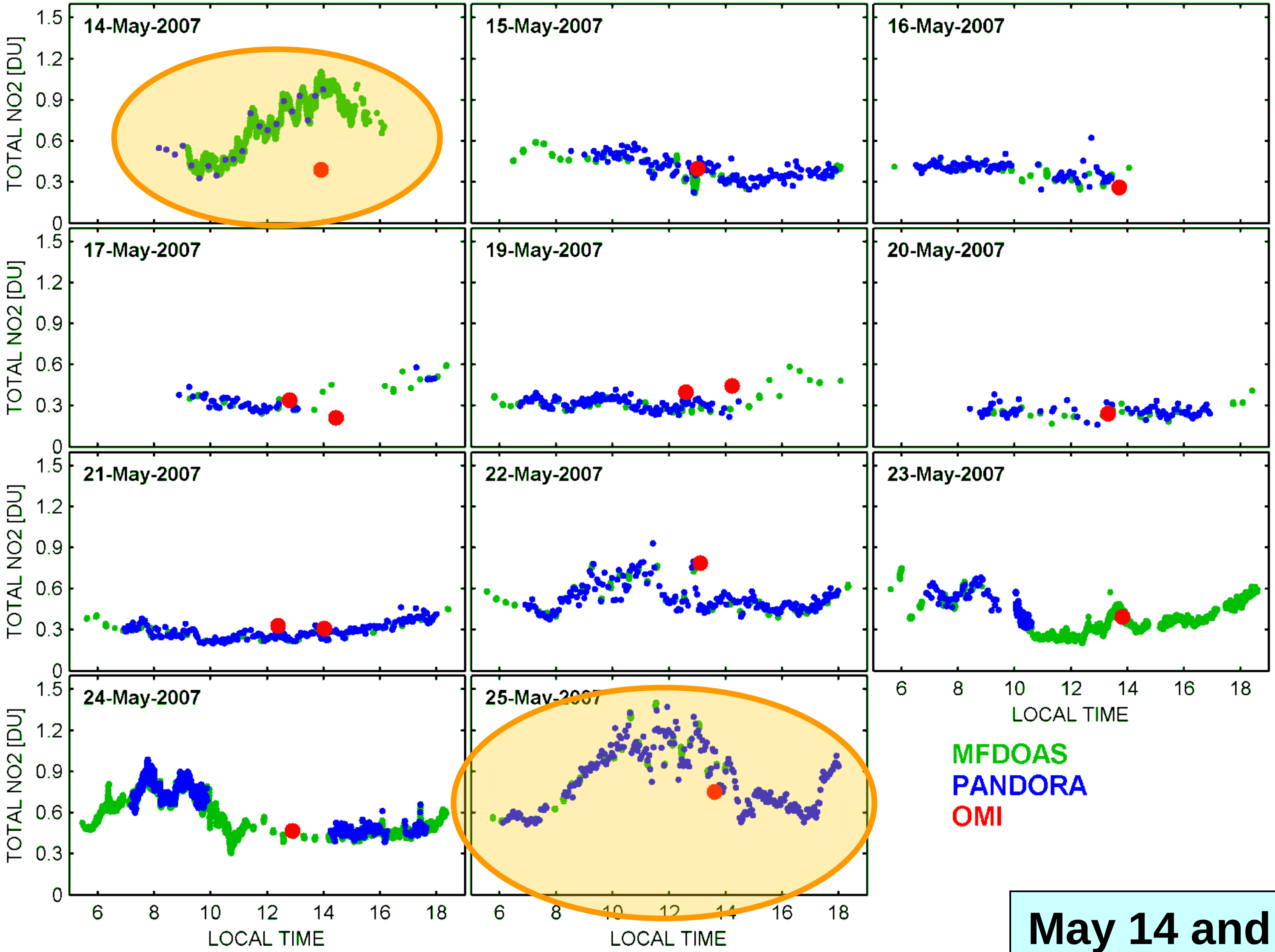
MFDOAS data from G. Mount and E. Spinei, WSU

Goddard Space Flight Center, MD, USA, 38.99 N, 76.84 W, May 2007



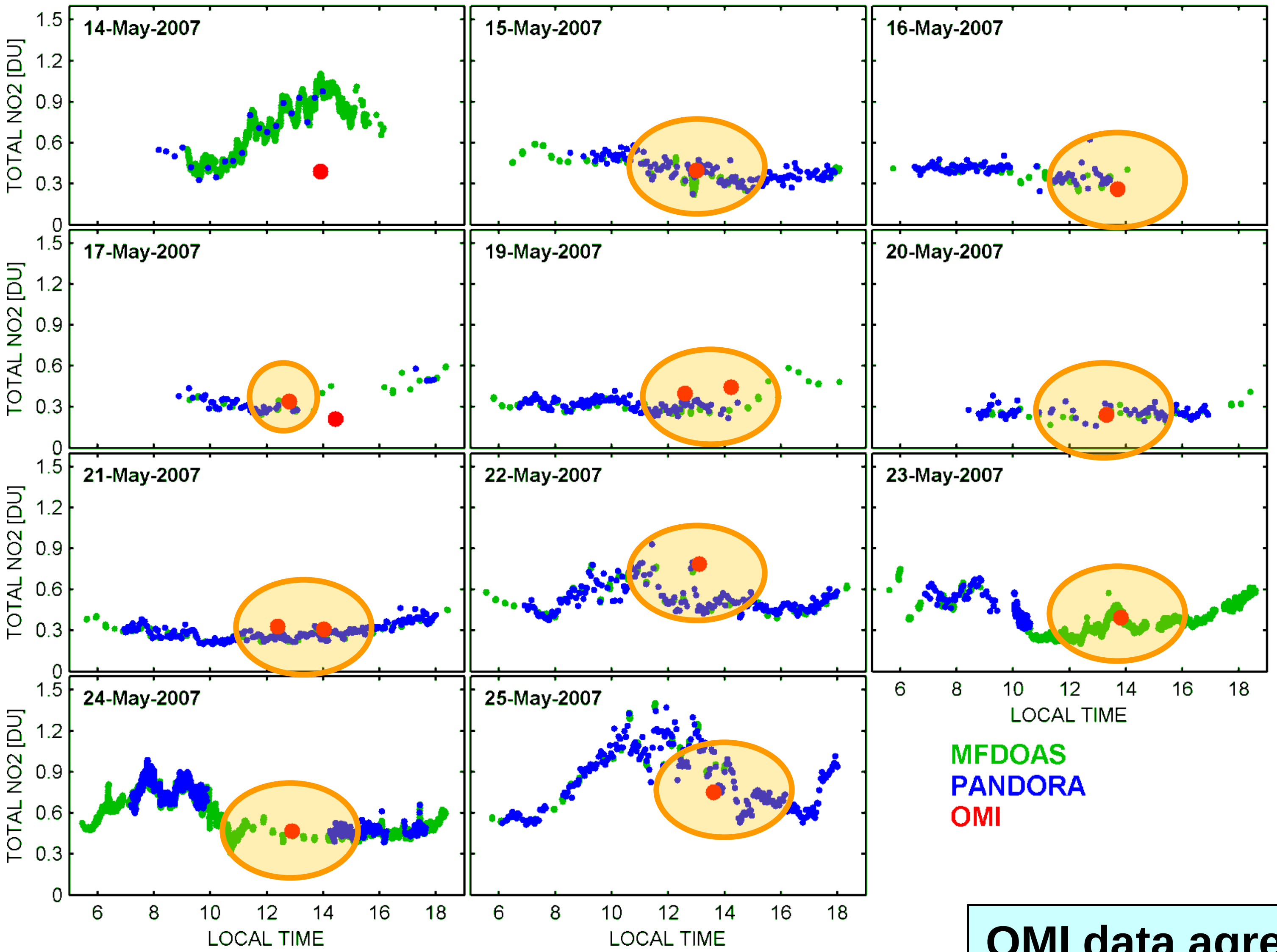
May 20 (Sunday) and May 21 (Monday) are rather clean

Goddard Space Flight Center, MD, USA, 38.99 N, 76.84 W, May 2007



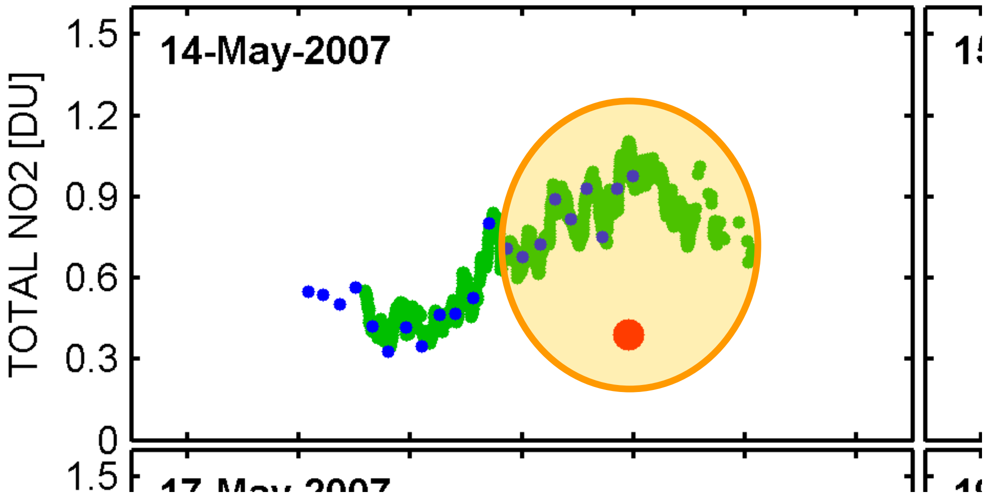
May 14 and 25 are heavily polluted

Goddard Space Flight Center, MD, USA, 38.99 N, 76.84 W, May 2007



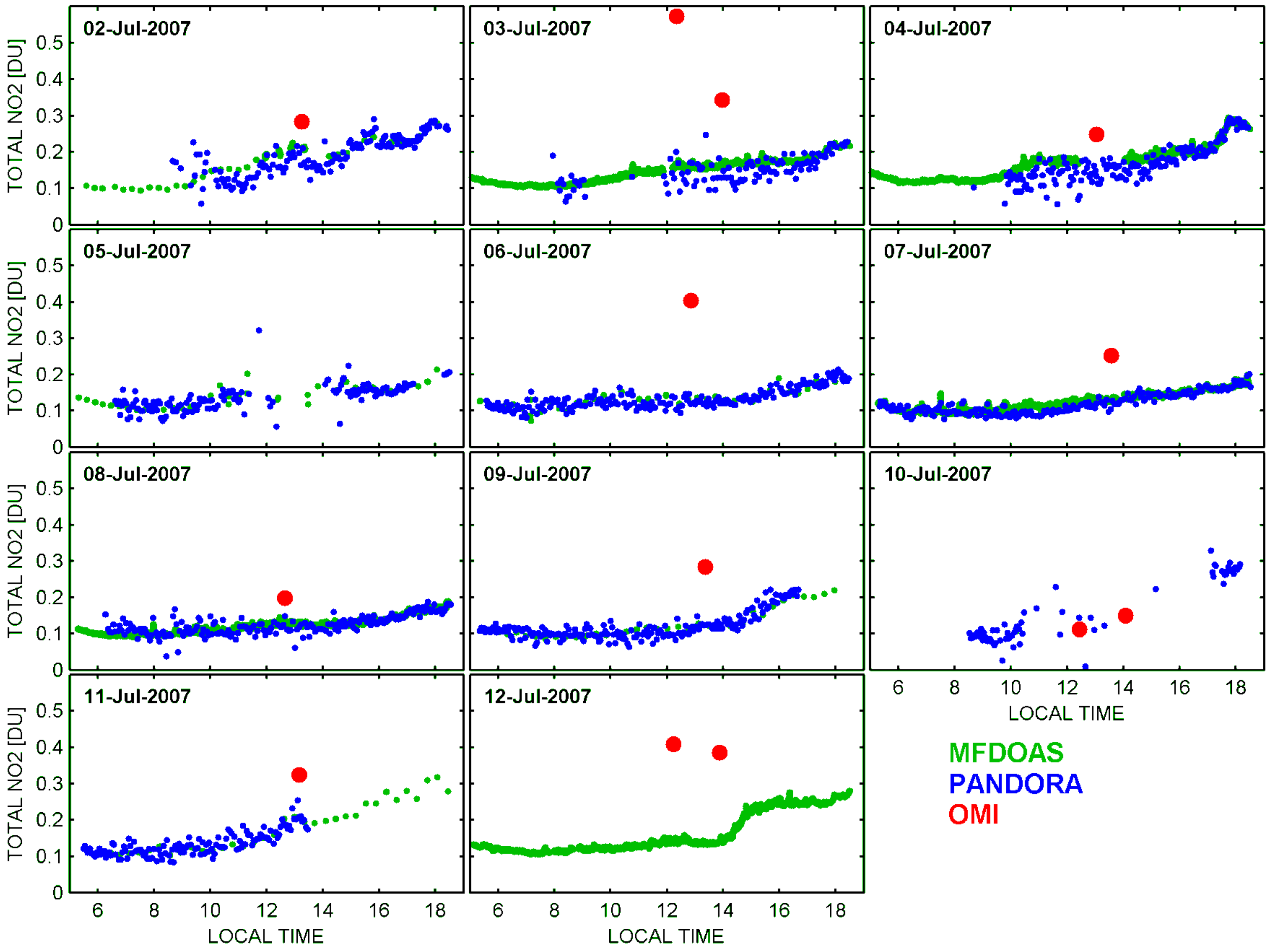
OMI data agree very well on all days but one

Goddard Space Flight Center, MD, USA, 38.99 N, 76.84 W, May 2007



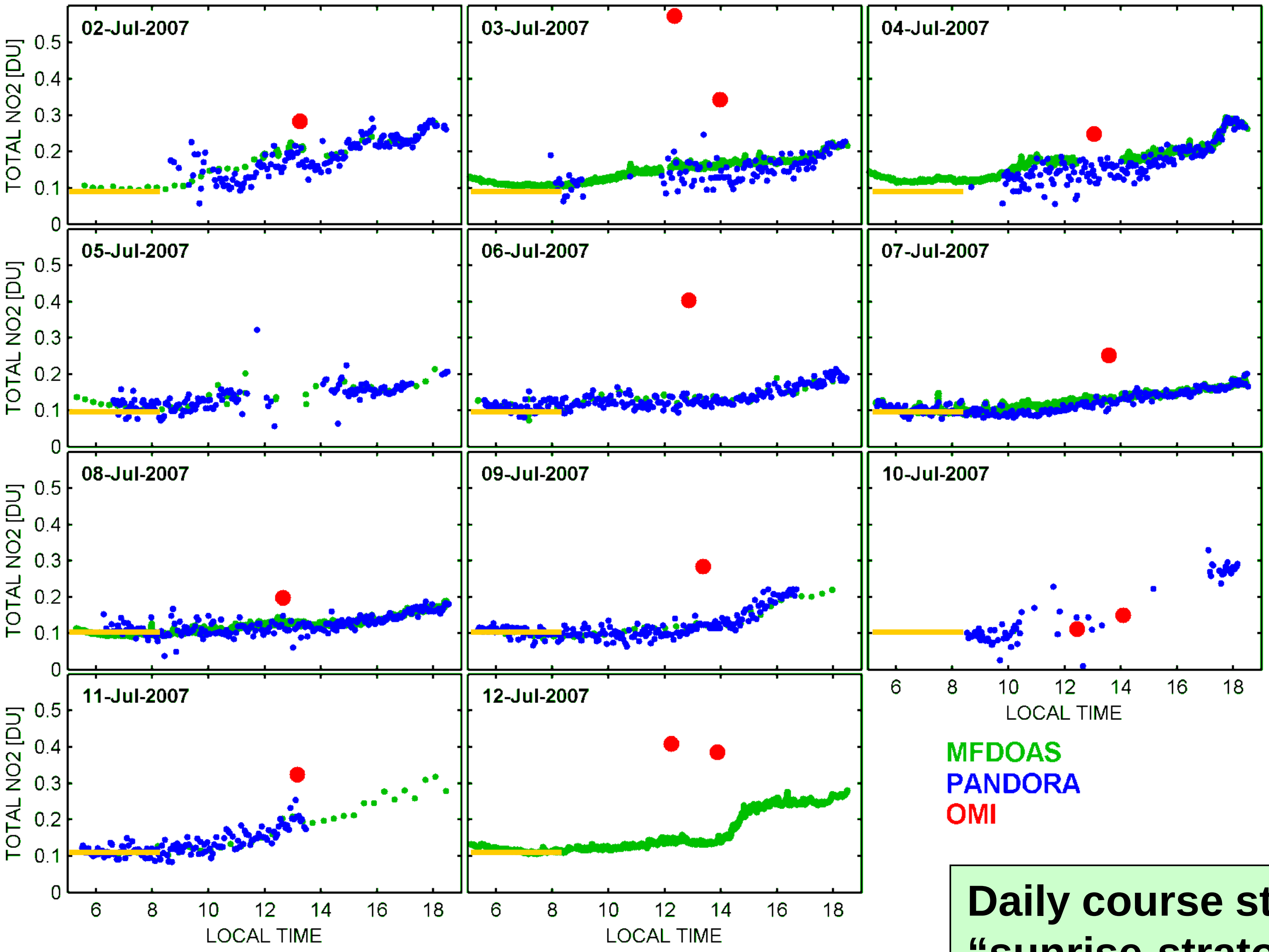
Low OMI value on May 14 is probably due to the pixel center being on the more rural East

JPL Table Mountain Facility, CA, USA, 34.38 N, 117.68 W, July 2007



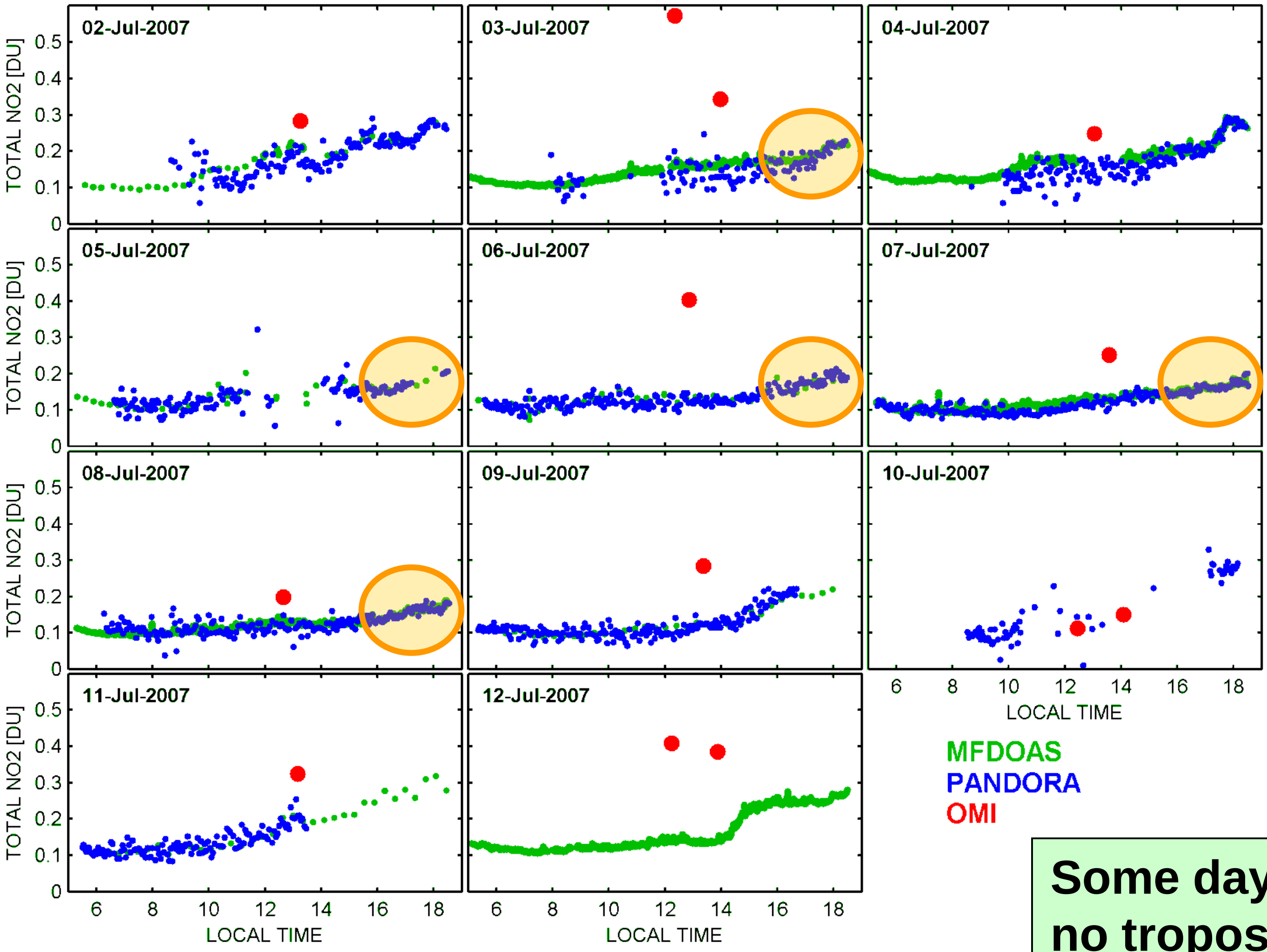
MFDOAS data from G. Mount and E. Spinei, WSU

JPL Table Mountain Facility, CA, USA, 34.38 N, 117.68 W, July 2007



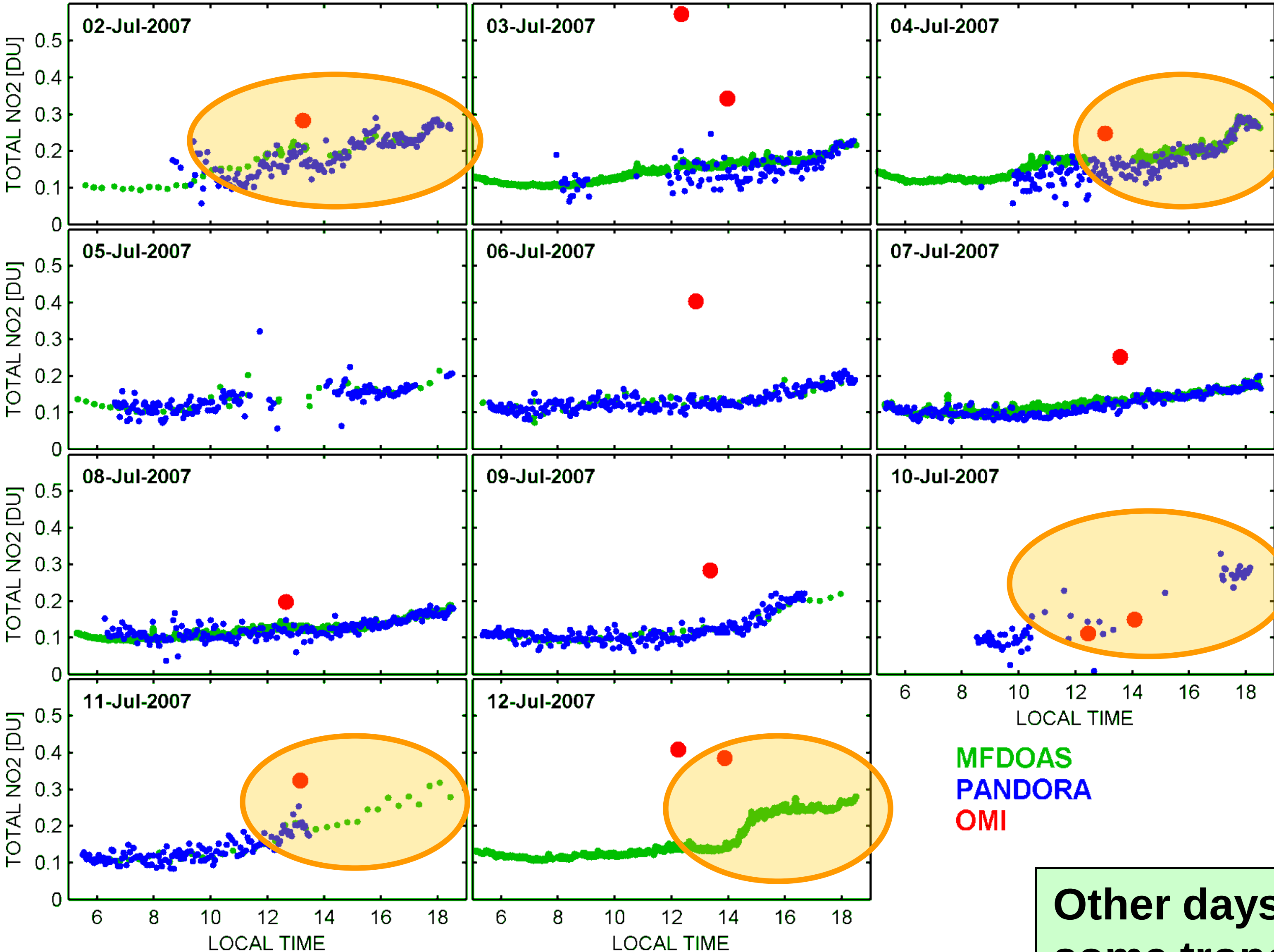
Daily course starts at "sunrise-stratospheric" levels (~0.1DU)

JPL Table Mountain Facility, CA, USA, 34.38 N, 117.68 W, July 2007



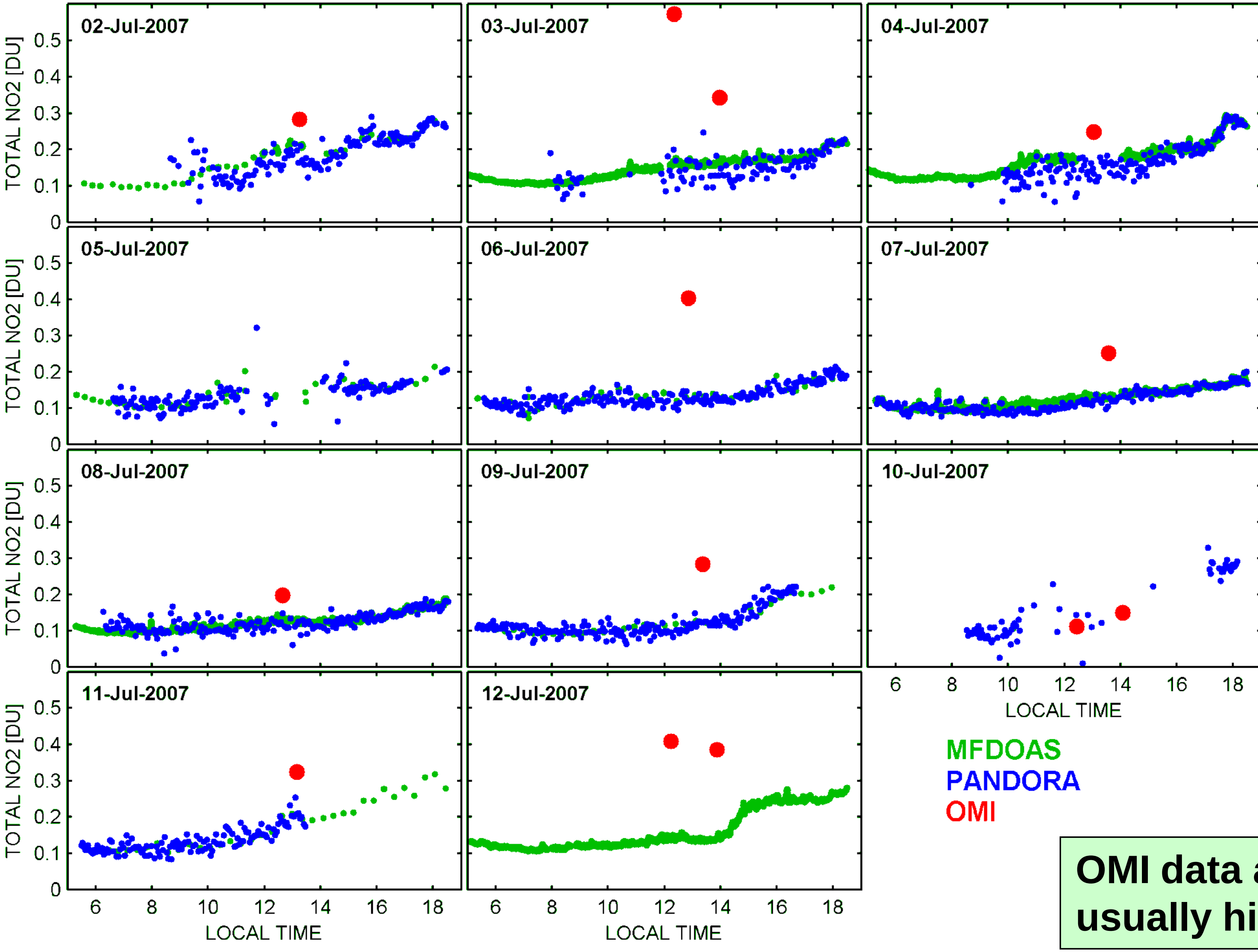
Some days show nearly no tropospheric NO_2; they end with typical "sunset-stratospheric" levels (~0.2DU)

JPL Table Mountain Facility, CA, USA, 34.38 N, 117.68 W, July 2007



Other days show some tropospheric NO_2 signal

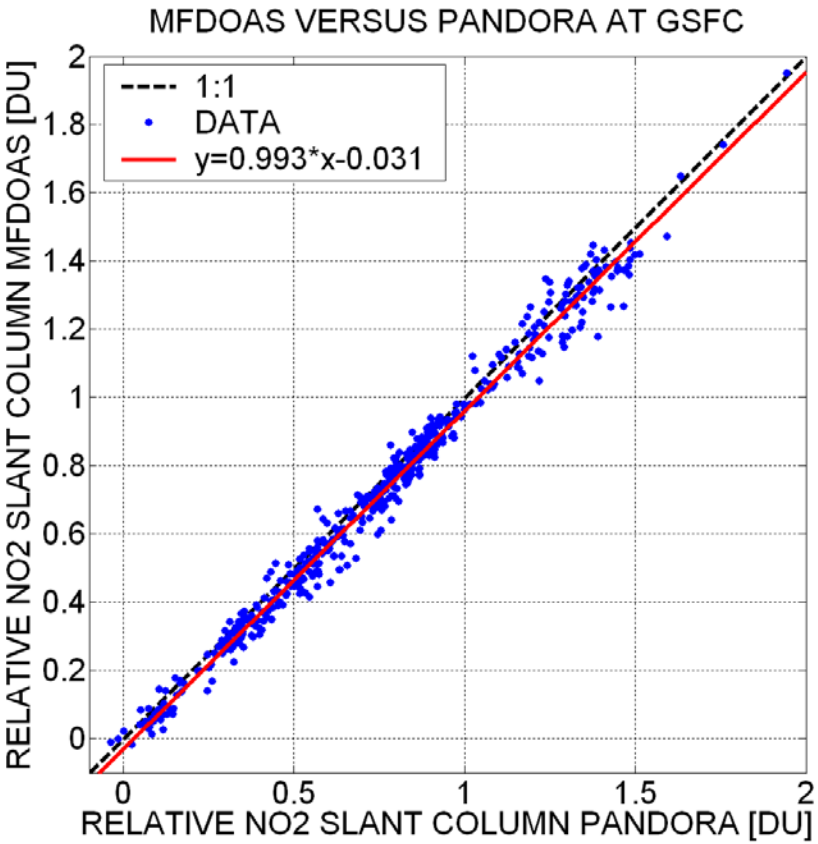
JPL Table Mountain Facility, CA, USA, 34.38 N, 117.68 W, July 2007

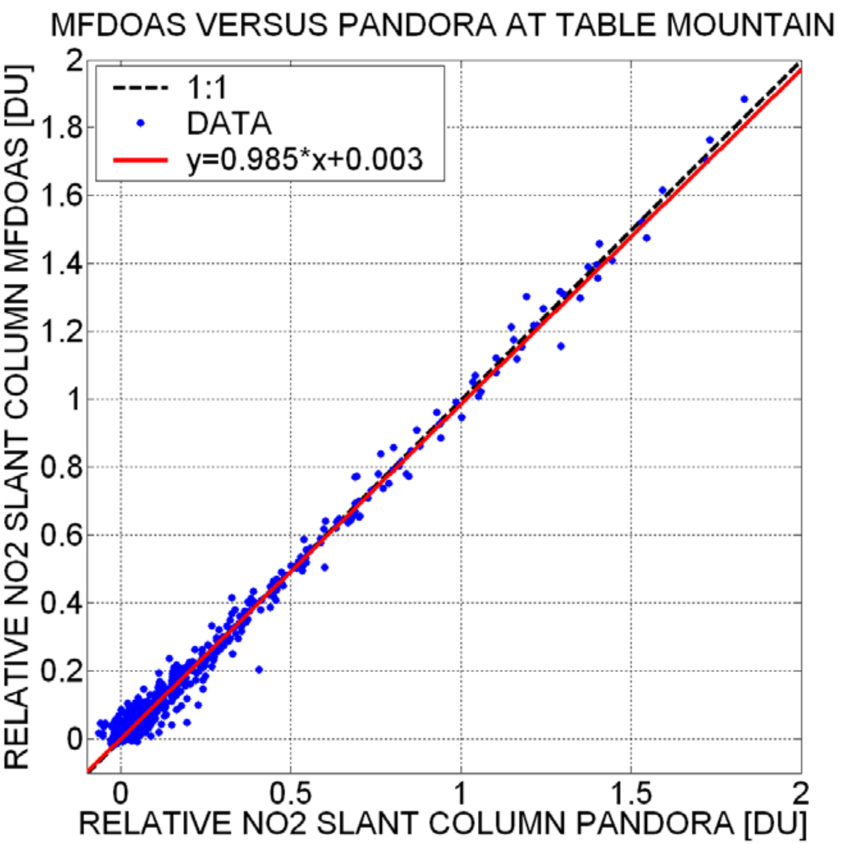


OMI data are usually high

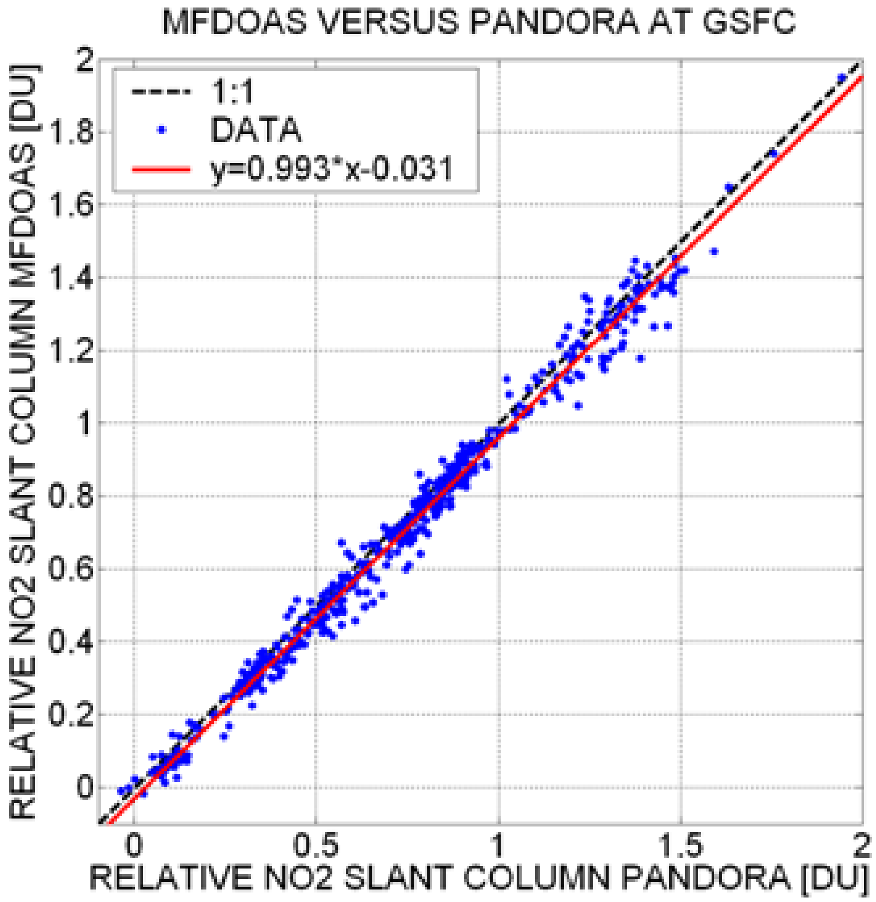
Comparison: Pandora versus MFDOAS

- Both data sets use reference spectrum taken at same time
- Window: PANDORA 370-500nm
  MFDOAS 405-430mn





Comparison between measured NO_2 slant columns from PANDORA-1 and MFDOAS over a 2 weeks period in May 2007 at Goddard Space Flight Center



How to Determine a Reference Spectrum for NO_2

1) Take the average of all the measured spectra over a certain time period as "first guess reference". This reference still includes the average slant column amount of all atmospheric species.

2) Determine the slant column amount included in the first guess reference. Two options:

- Use measurements from a collocated calibrated instrument (e.g. a Brewer spectrometer for the total ozone column)
- Apply "Minimum Amount Langley Extrapolation" (→ next slide).

3) Add this amount to obtain the final reference spectrum, which is assumed to be extinction-free.

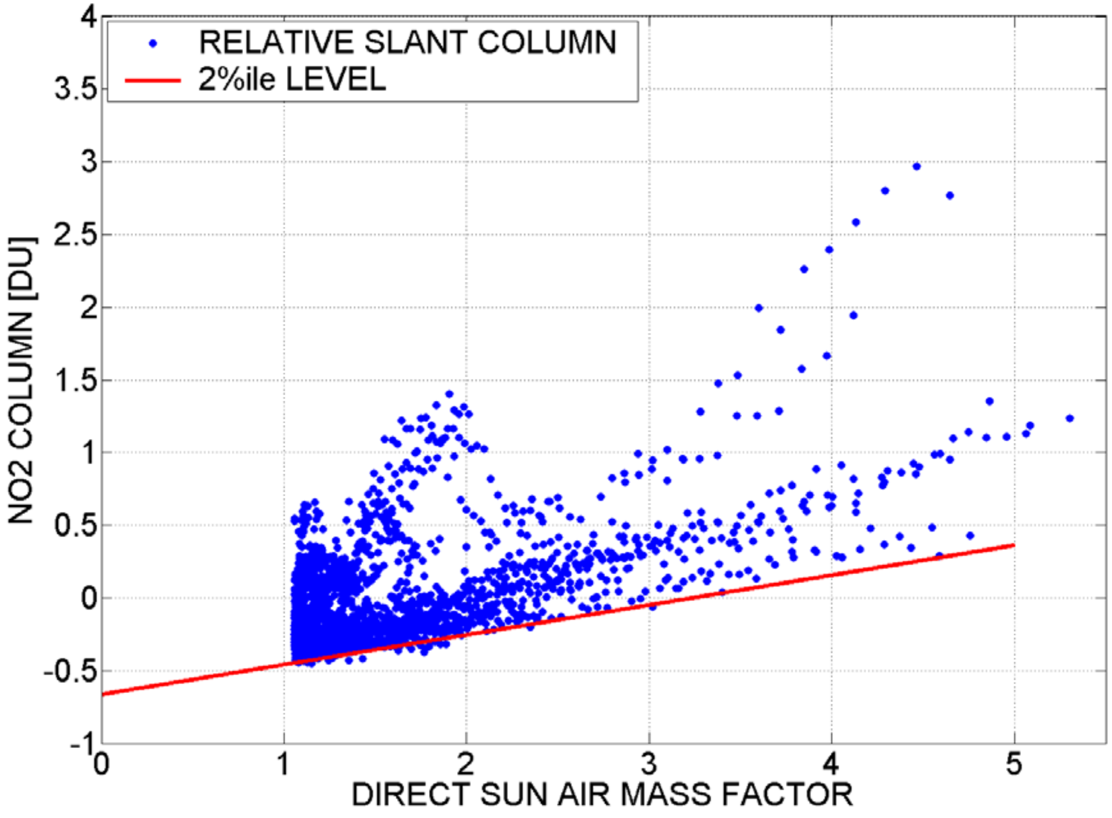
Minimum Amount Langley Extrapolation

Standard Langley Extrapolation

→ Assumes that the **vertical column amount** of an atmospheric parameter is independent of the air mass factor during a certain time period

Minimum Amount Langley Extrapolation

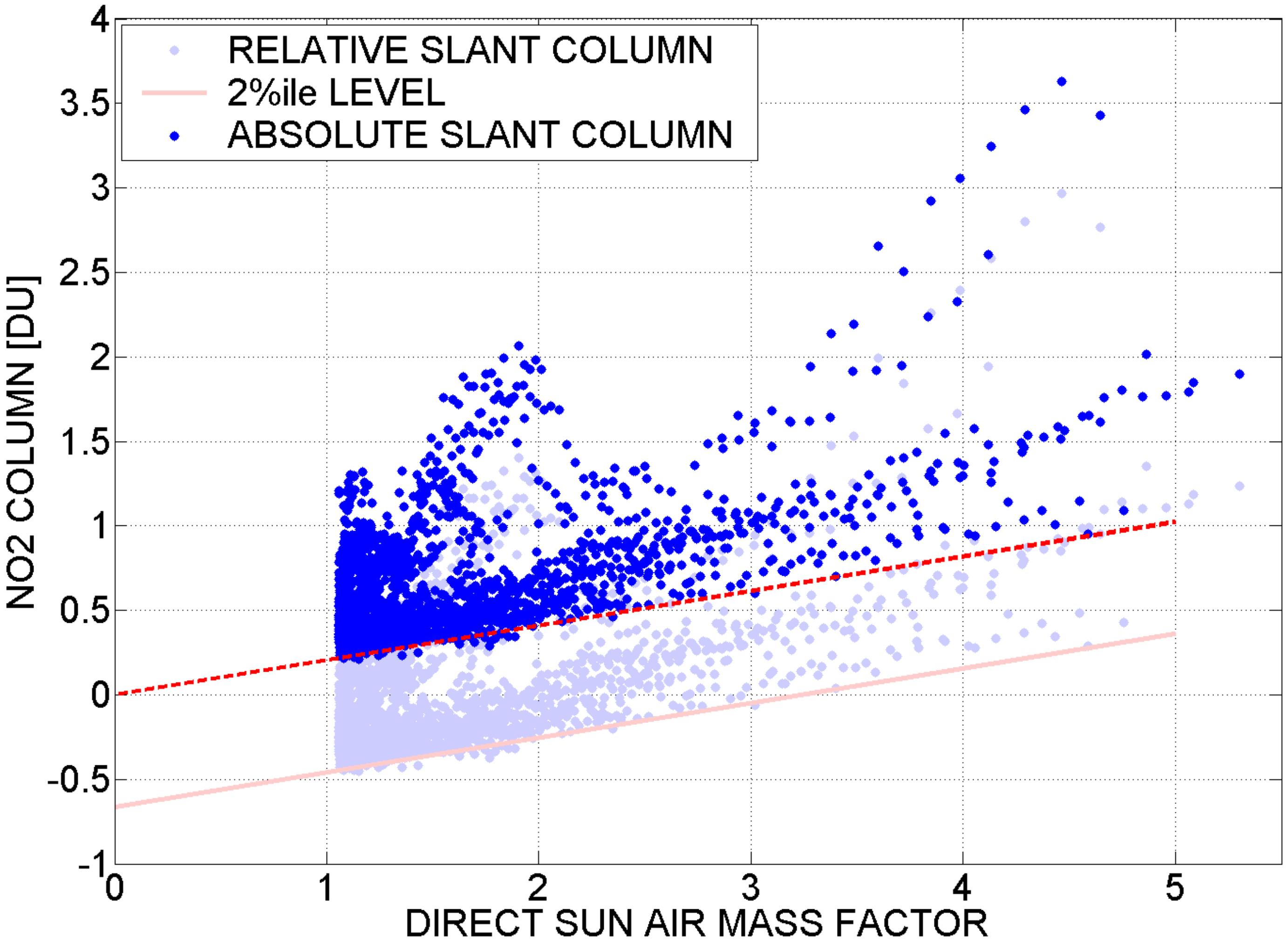
→ Assumes that the **minimum vertical column amount** of an atmospheric parameter is independent of the air mass factor during a certain time period



NO_2 slant column retrievals during SCOUT-O3 campaign using first guess reference spectrum

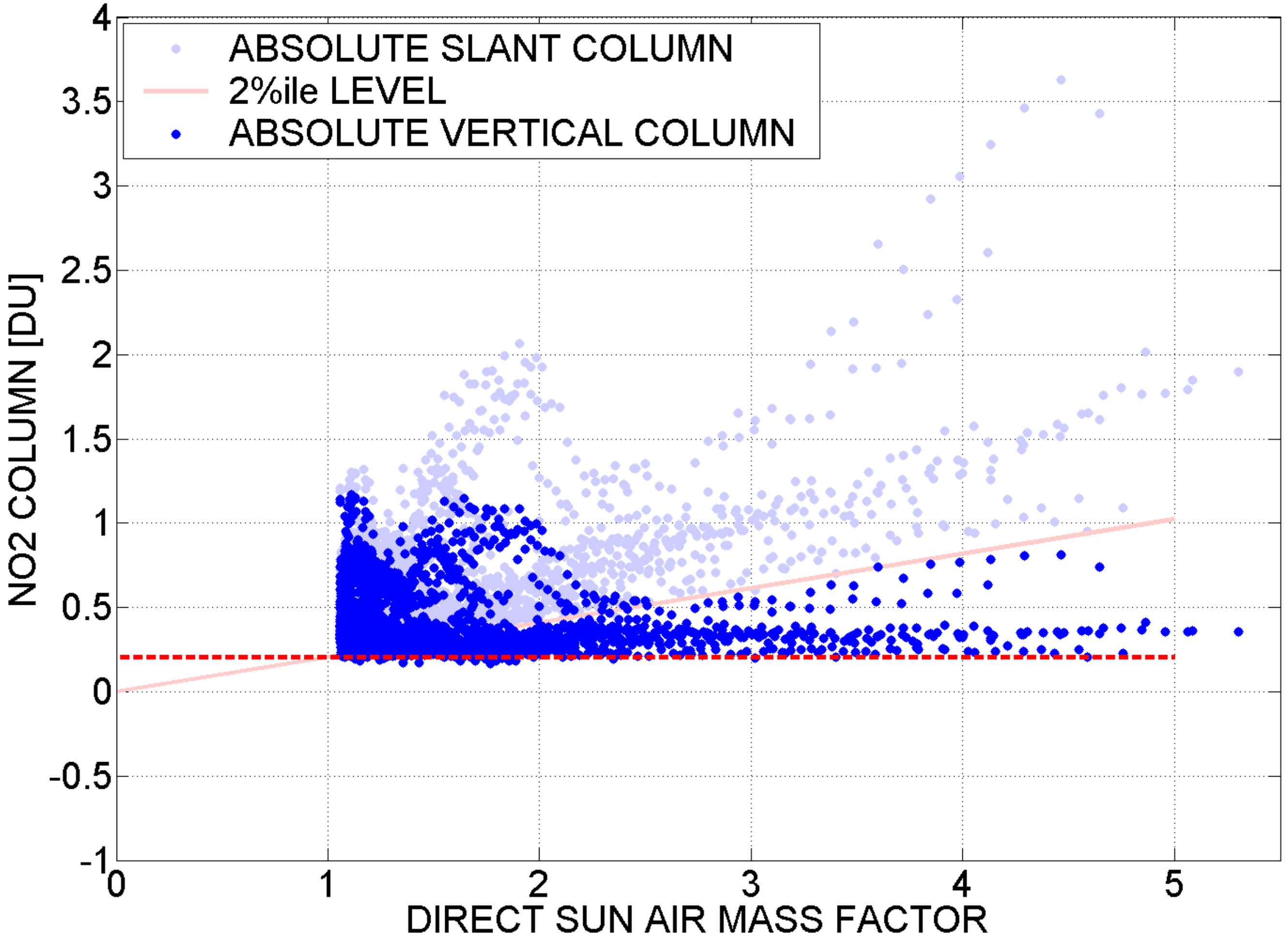
From Relative Slant Column to Absolute Slant Column

The true slant column must be zero when the air mass factor is zero



From Absolute Slant Column to Absolute Vertical Column

Simply divide by the air mass factor.
For NO_2: baseline is stratospheric background



Reference spectrum

1) Take the average of all the measured spectra over a certain time period as “first guess reference”. This reference still includes the average slant column amount of all atmospheric species.

2) Determine the slant column amount included in the first guess reference. Two options:

- Use measurements from a collocated calibrated instrument (e.g. a Brewer spectrometer for the total ozone column)
- Apply “Minimum Amount Langley Extrapolation” (→ next slide).

3) Add this amount to obtain the final reference spectrum, which is assumed to be extinction-free.

Minimum Amount Langley Extrapolation

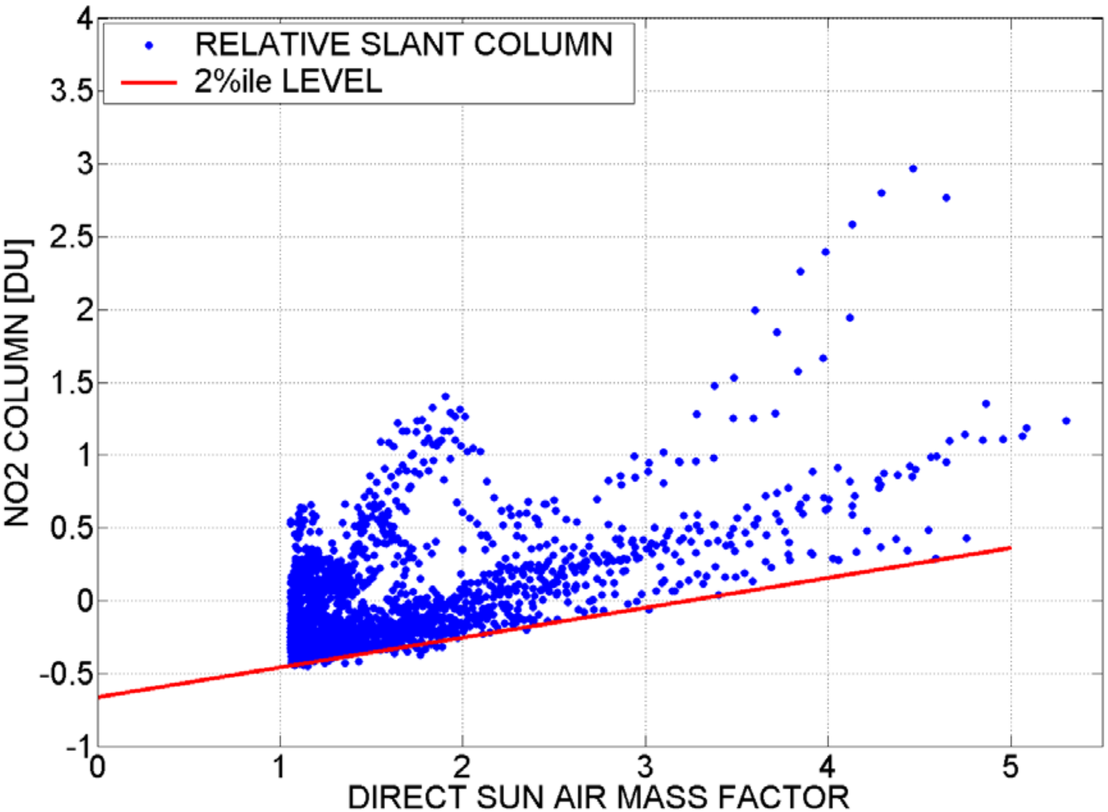
Standard Langley Extrapolation

→ Assumes that the **vertical column amount** of an atmospheric parameter is independent of the air mass factor during a certain time period

Minimum Amount Langley Extrapolation

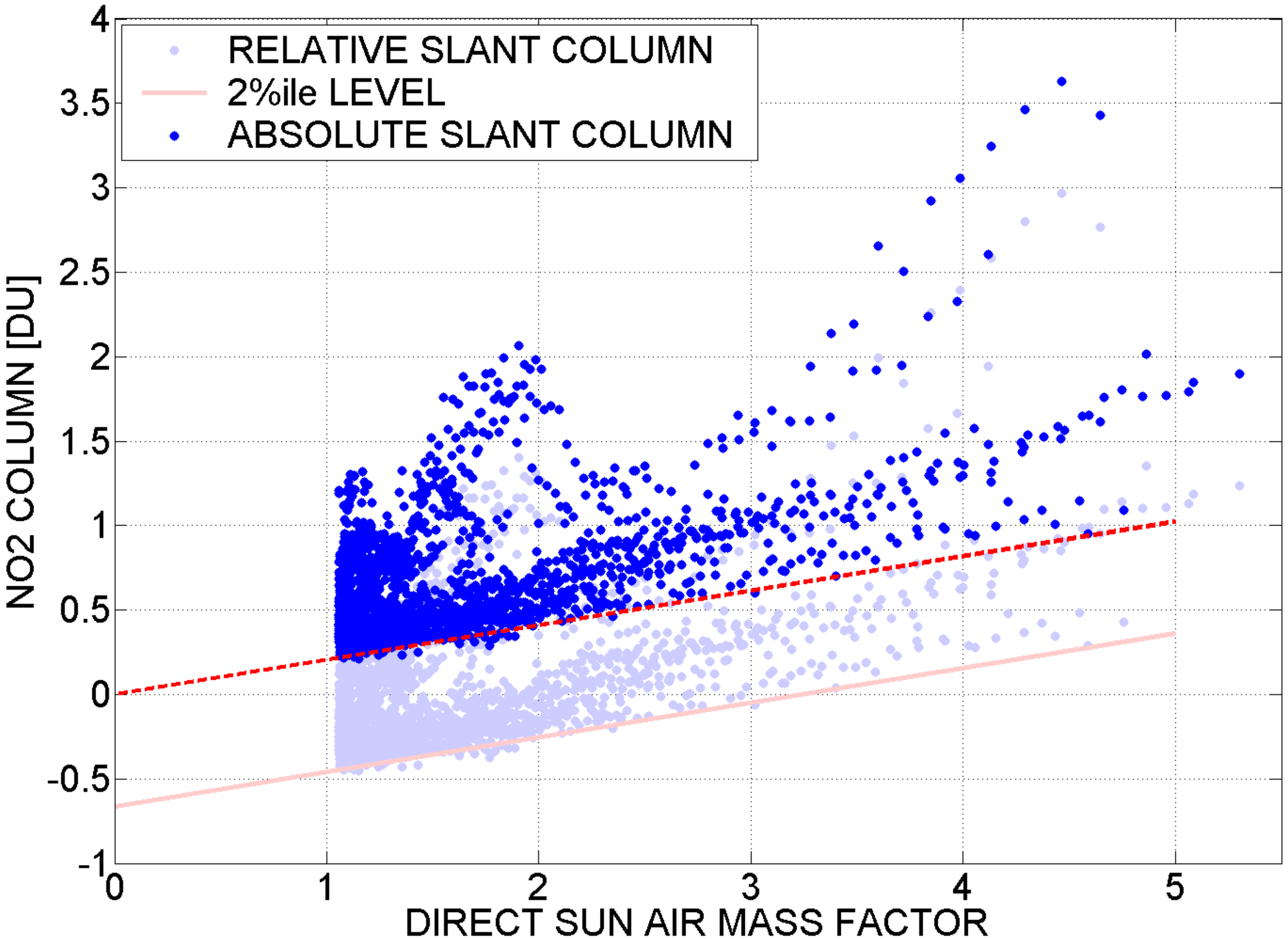
→ Assumes that the **minimum vertical column amount** of an atmospheric parameter is independent of the air mass factor during a certain time period

NO_2 slant column retrievals during SCOUT-O3 campaign using first guess reference spectrum



From Relative Slant Column to Absolute Slant Column

The true slant column must be zero when the air mass factor is zero



From Absolute Slant Column to Absolute Vertical Column

Simply divide by the air mass factor.
For NO_2: baseline is stratospheric background