Atmospheric remote sounding by stellar occultation: the GOMOS experiment

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IASB remote sensing/aerosol team

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- Christine Bingen
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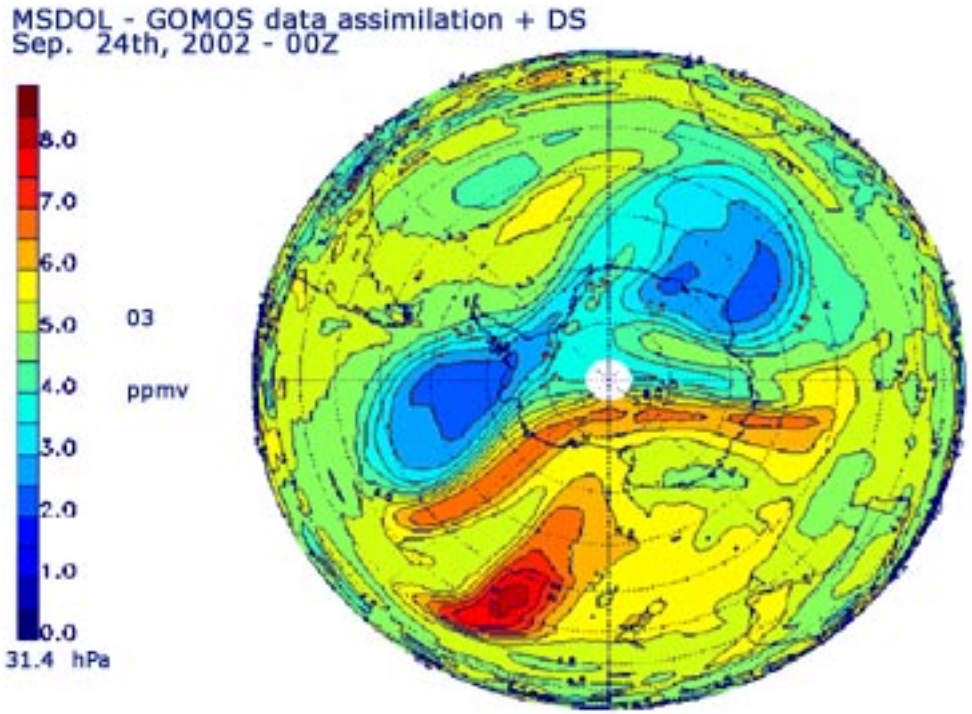
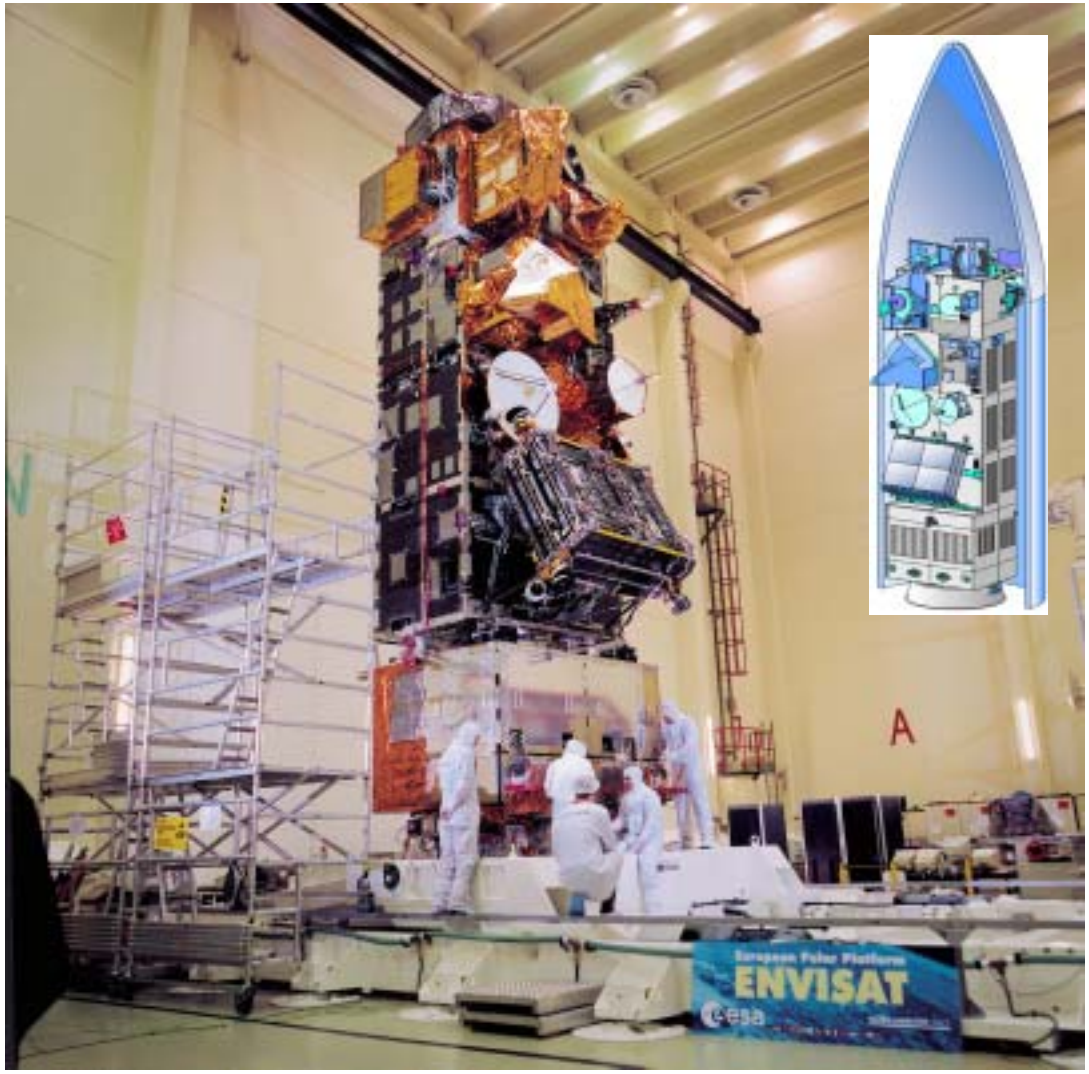
Main collaborations: ESA, SA(Verrières), FMI(Helsinki), Univ. Waterloo (Waterloo/Canada), NASA-Langley, Univ. Lille

Assimilated ozone field



A technical european challenge: ENVISAT



- ***Dimensions***
  - Au lancement:
    - hauteur 10.5 m
    - diamètre 4.6 m
  - En orbite:
    - 26m x 10m x 5m

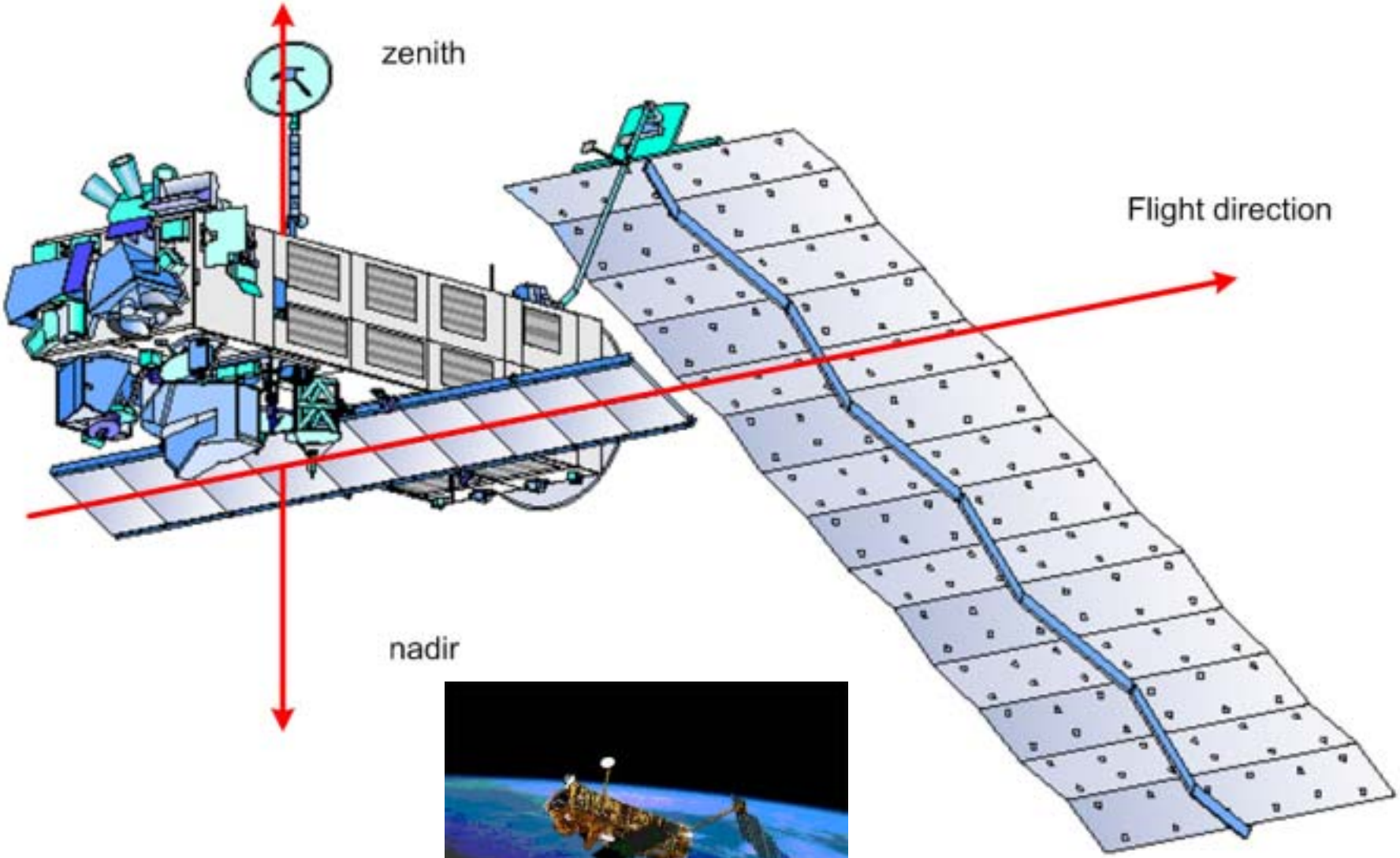
- ***Masse***

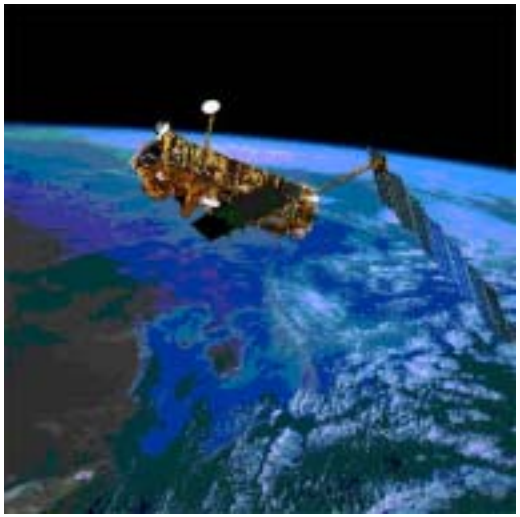
Totale	8140 Kg
Charge utile	2050 Kg

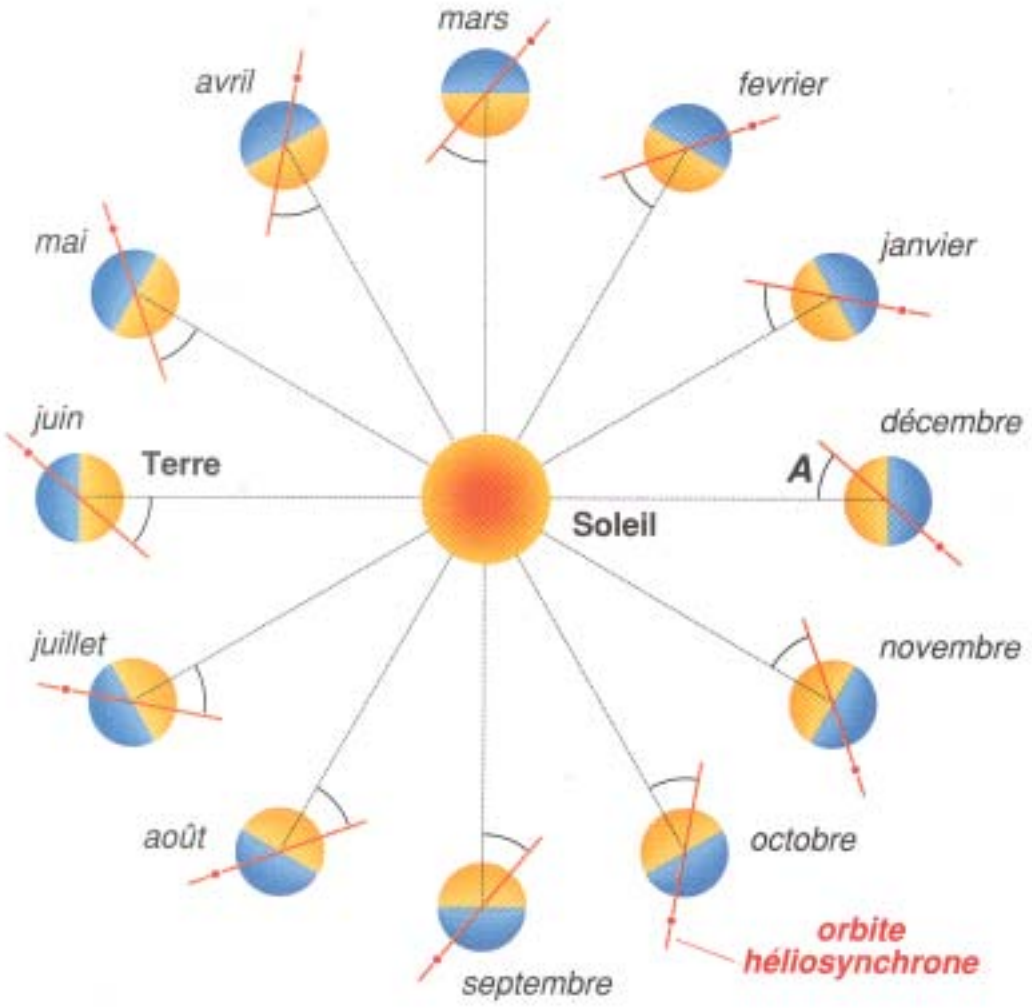
- ***Puissance électrique***
  - 1 panneau solaire
    - 6500 W
  - Consommation moyenne:

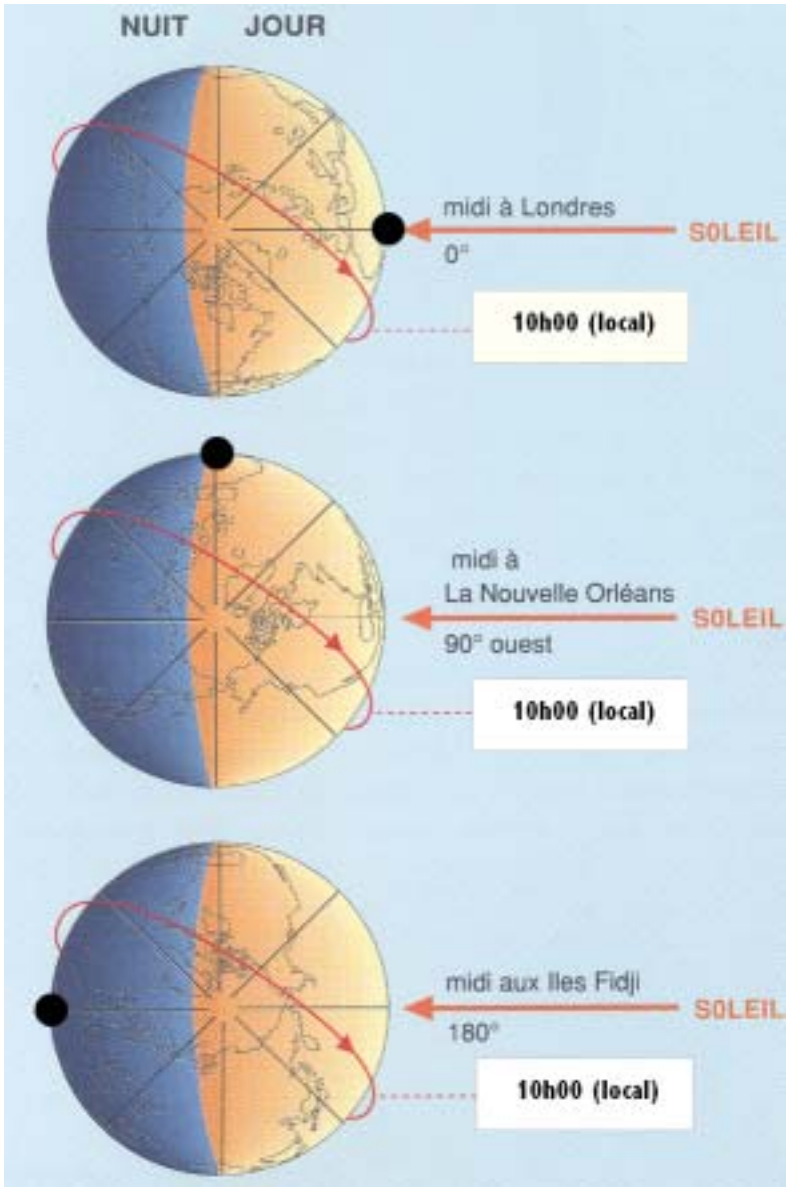
	Soleil (watts)	Ombre (watts)
Charge	1700	1750
Satellite	3275	2870

- ***Lanceur***
  - Ariane 5

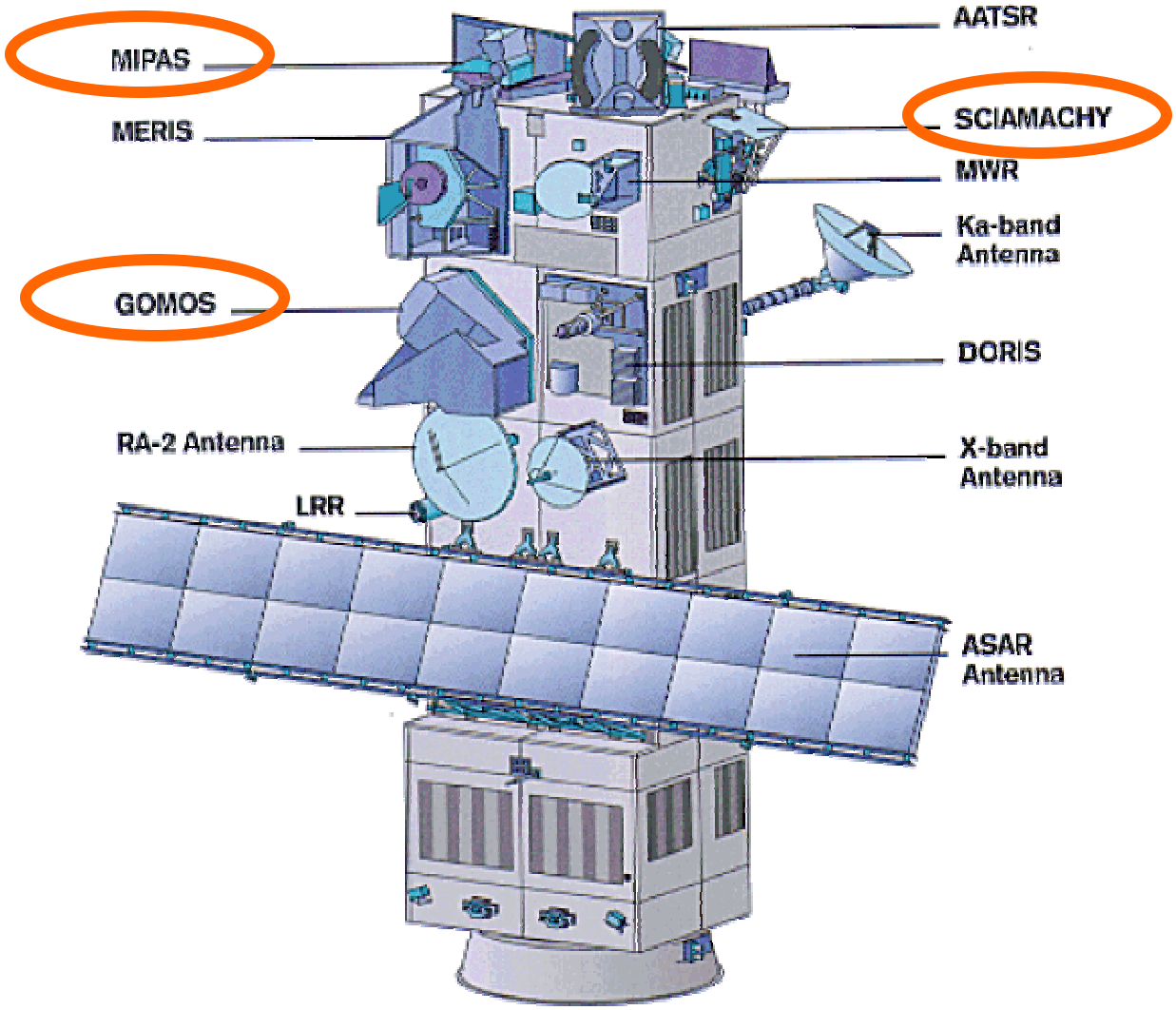

zenith
Flight direction
nadir







Heliosynchronous orbit



MIPAS, SCIAMACHY, GOMOS

ENVISAT Atmospheric Chemistry

GOMOS

vertical profiles
stellar occultations, UV-visible, near IR
O3, NO2, NO3, OClO, H2O,T,aerosols

MIPAS

vertical profiles
limb emission in thermal IR
O3, H2O, NO2, CH4, HNO3, N2O, P, T

SCIAMACHY

total columns (+ vertical profiles off-line)
nadir and limb scattering + solar occulations
UV-visible, Near IR
O3, NO2, NO3, OClO, H2O, BrO, H2CO, CO, CH4, aerosols, clouds

Stellar Occultations from GOMOS on ENVISAT:overview and first results

GOMOS INSTRUMENT ESL TEAMS

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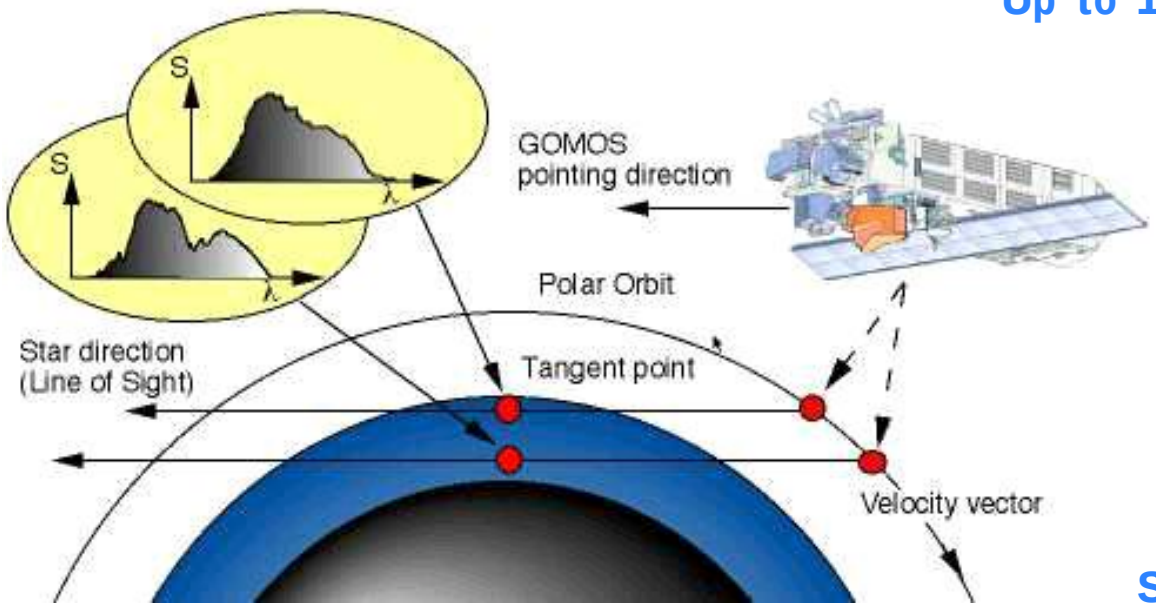
GOMOS principle (1)



Below 10 km
Up to 120 km

One star spectrum every 0.5 s

Pointing information 100 Hz

Scintillation information 1000 Hz

GOMOS Observation Geometry

Pointing range

Azimuth: -10 to 90 degree
w.r.t anti-flight direction
Elevation: 62 to 68 degree
from nadir direction

Tracking range

Azimuth: 7.4 degree
Elevation: 6.5 degree

Rallying Speed

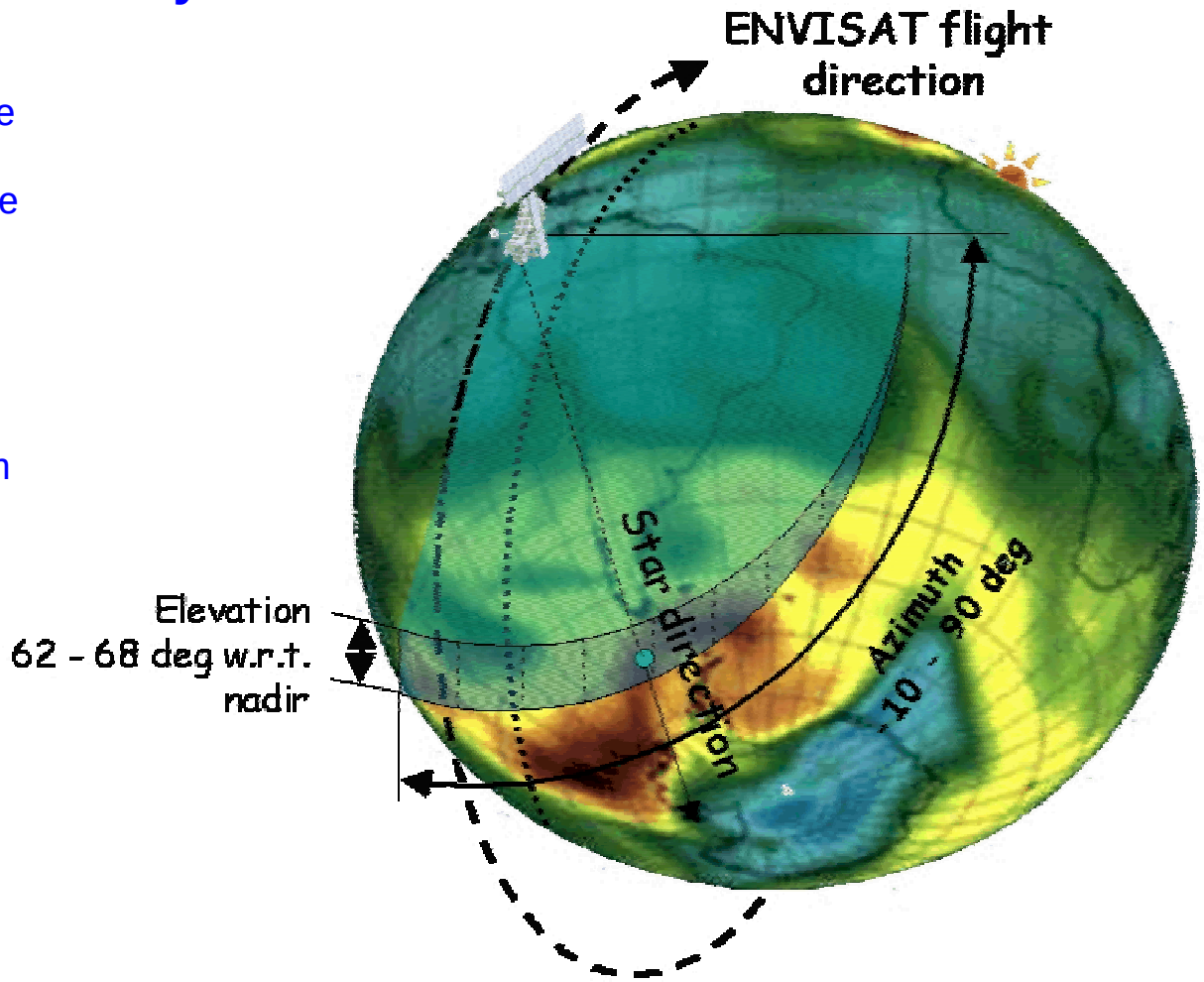
50 degree star separation
= 24 Seconds

Max Tracking Duration

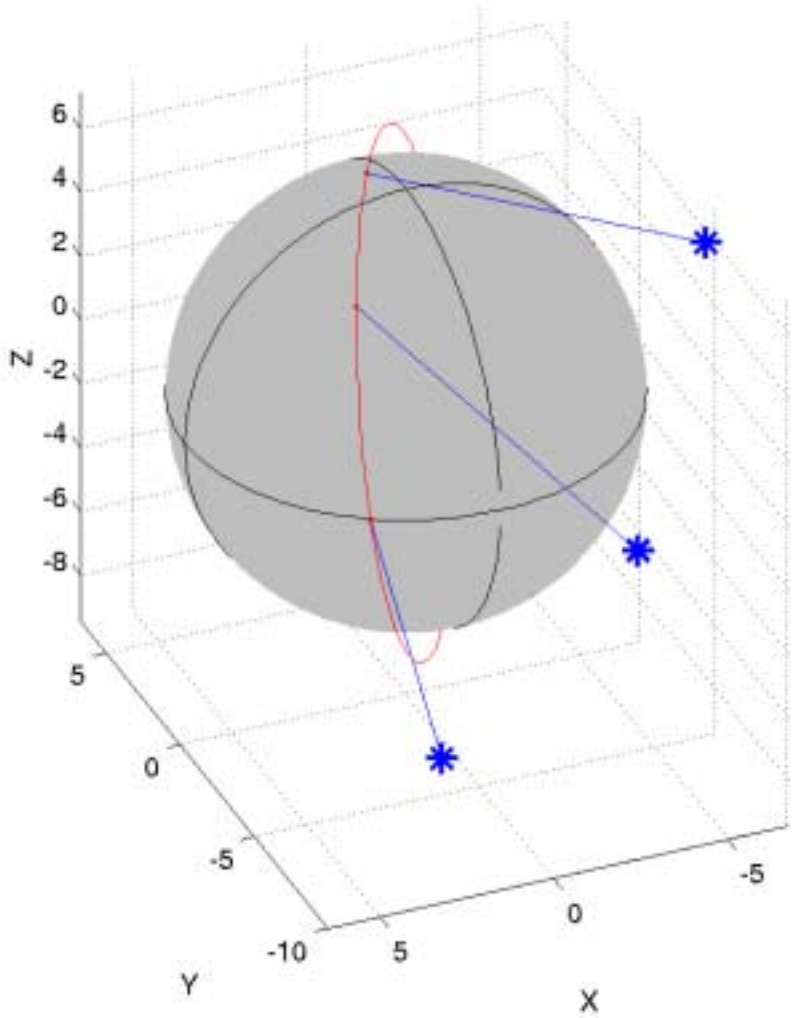
250 Seconds

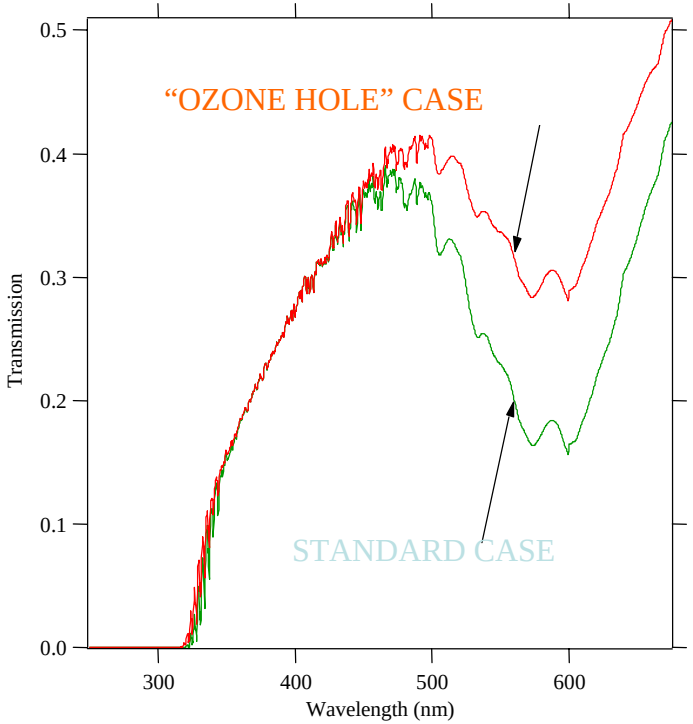
Tracking altitude

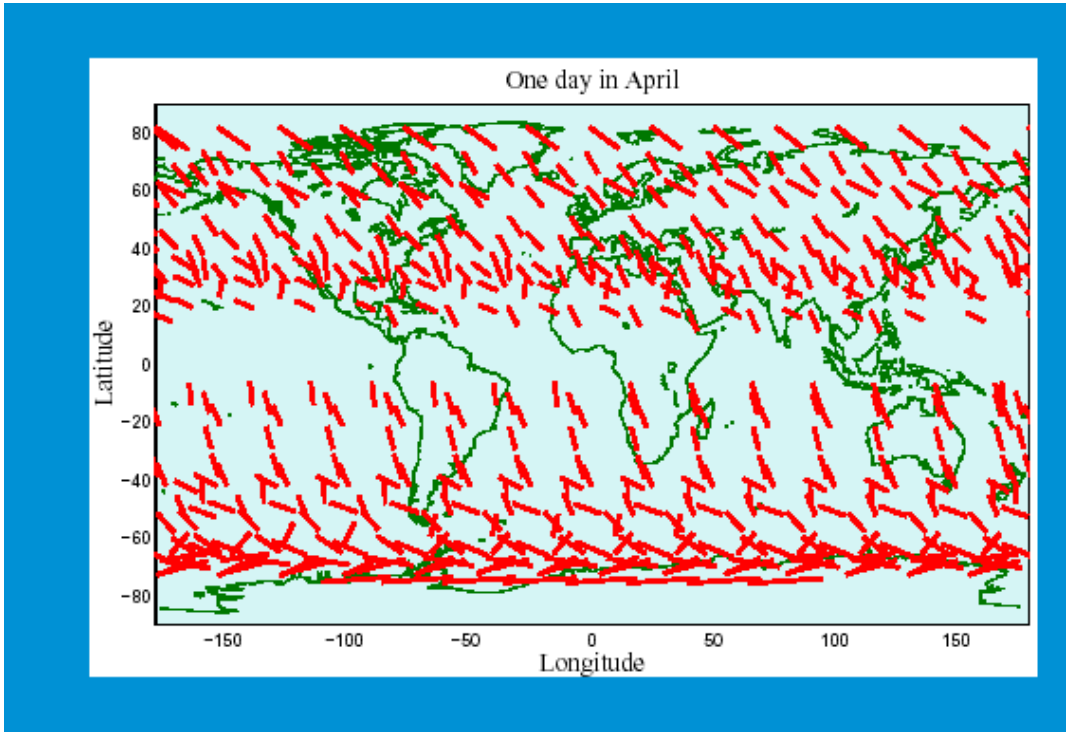
-15 to ~248 Km



Star occultation may be vertical, oblique or “tangent”...




"OZONE HOLE" CASE
STANDARD CASE
Transmission
Wavelength (nm)
0.0
0.1
0.2
0.3
0.4
0.5
300
400
500
600


One day in April
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150

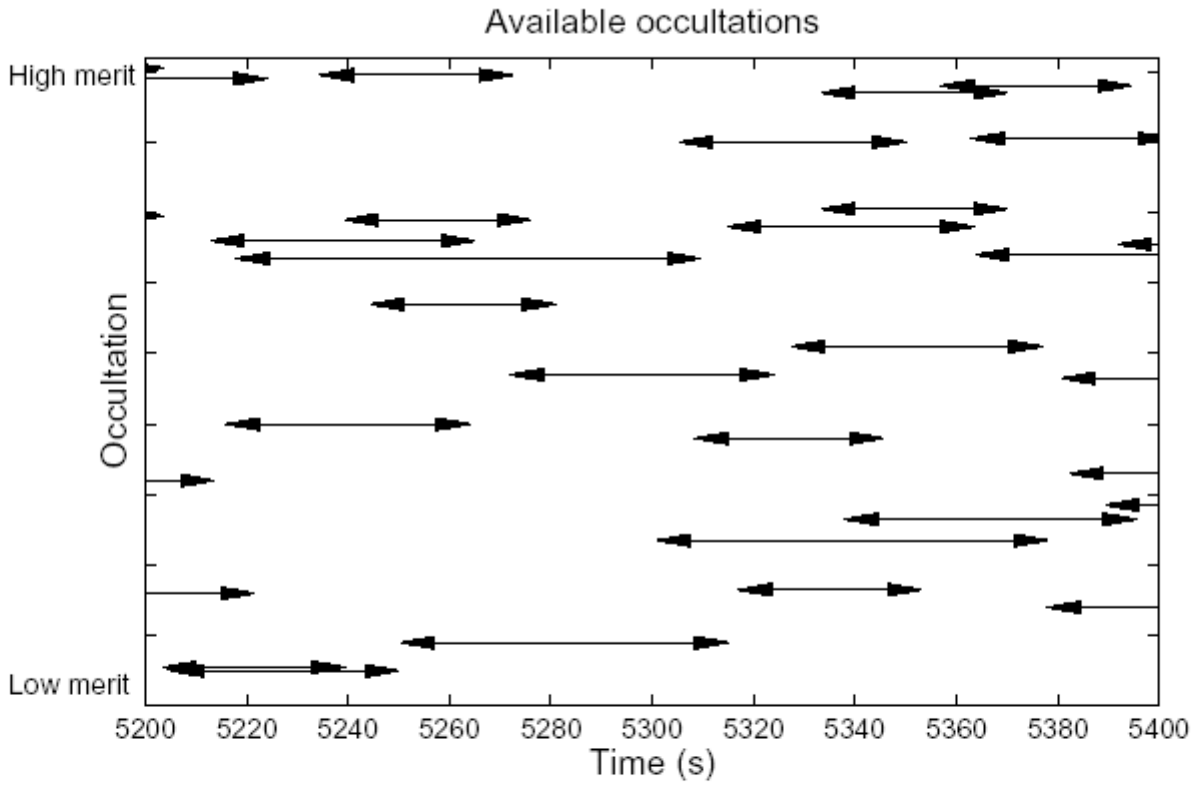
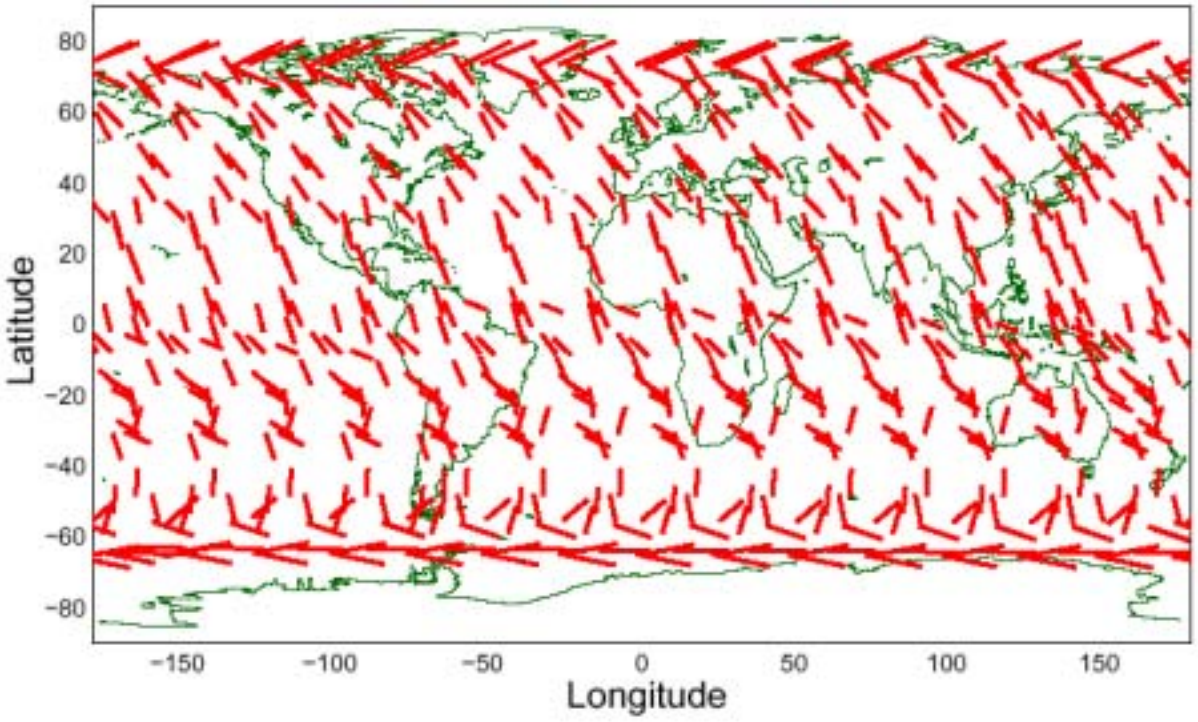
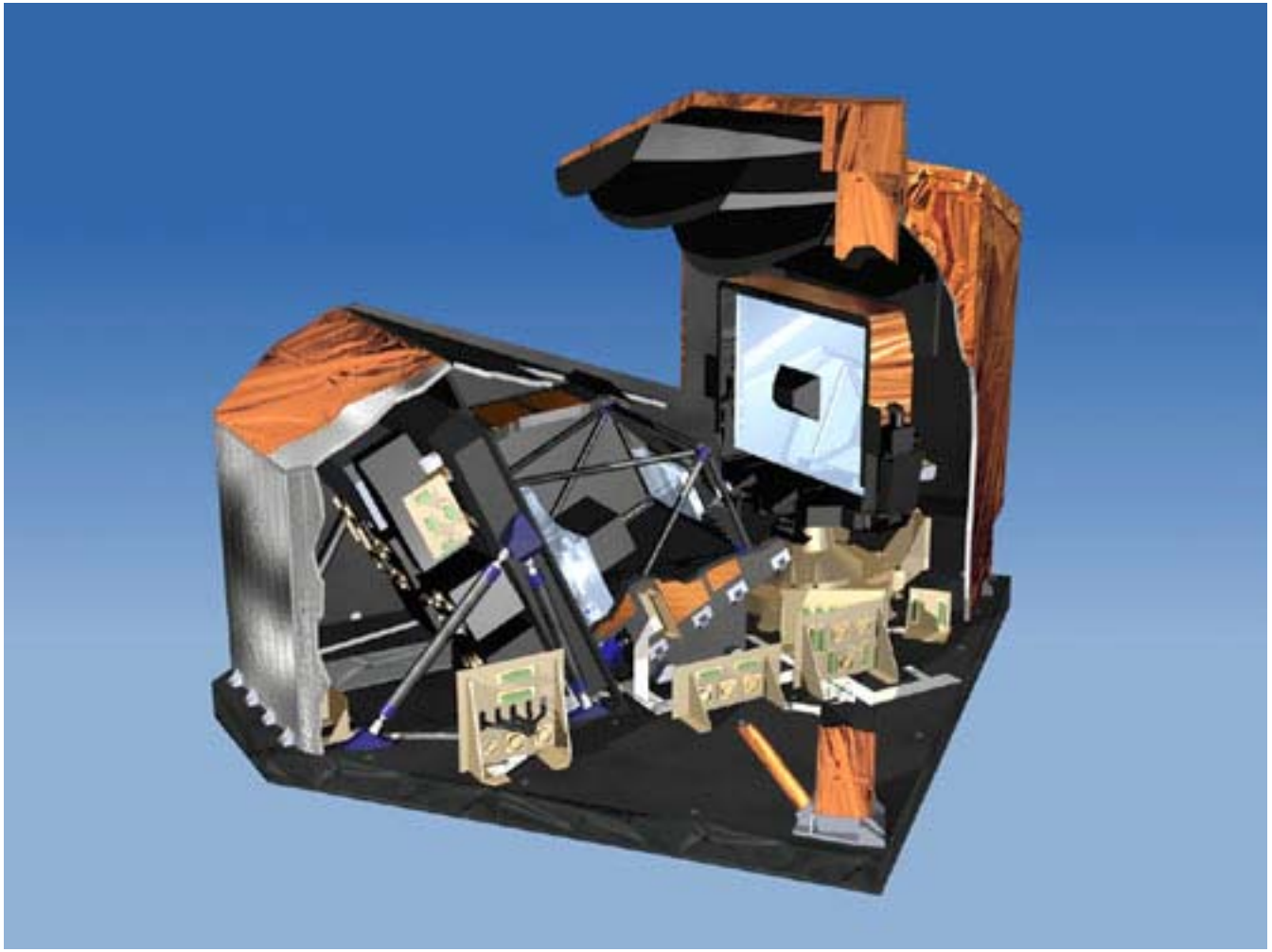


Figure 6.3. An example of a 200 s. period from the Envisat orbit during March. Occultations are indicated by arrows in time. The vertical position indicates the merit value of the occultation with respect of ozone monitoring.

GOMOS Global Coverage

Example of the global coverage of GOMOS using the Cal/Val based selection of stars and after one day of measurements





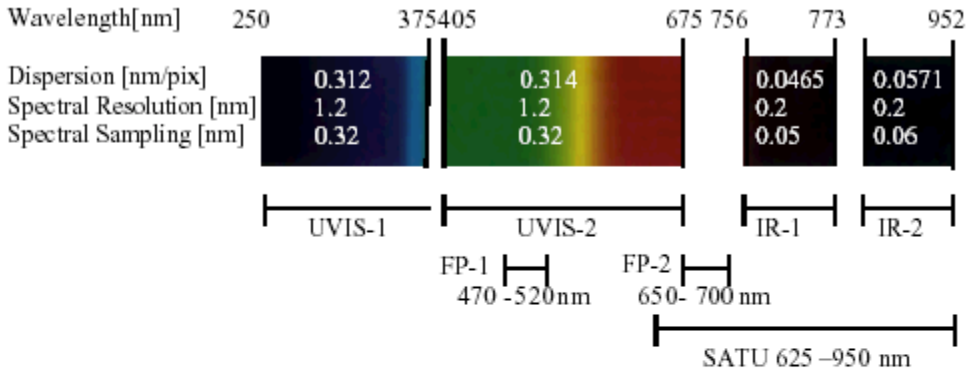
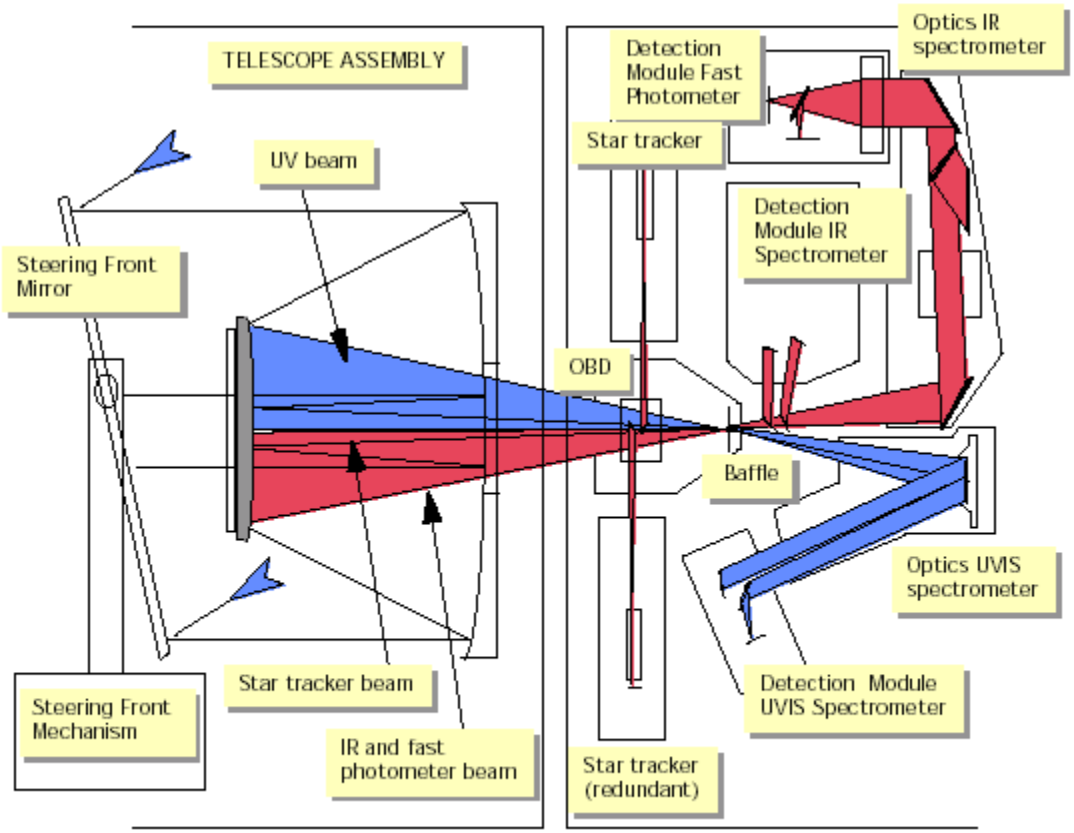
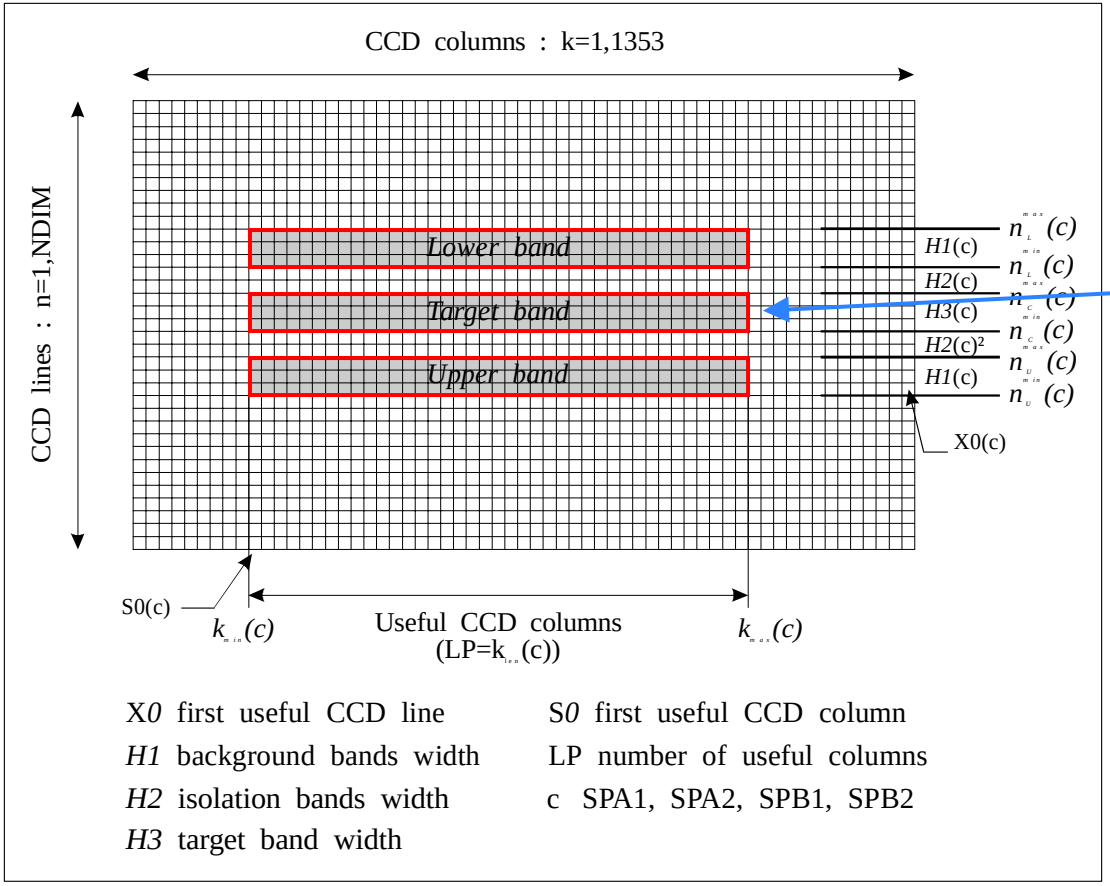


Figure 4.3. Spectral coverage of the GOMOS detection units.



GOMOS principle (2)



X*0* first useful CCD line
H1 background bands width
H2 isolation bands width
H3 target band width

S*0* first useful CCD column
LP number of useful columns
c SPA1, SPA2, SPB1, SPB2

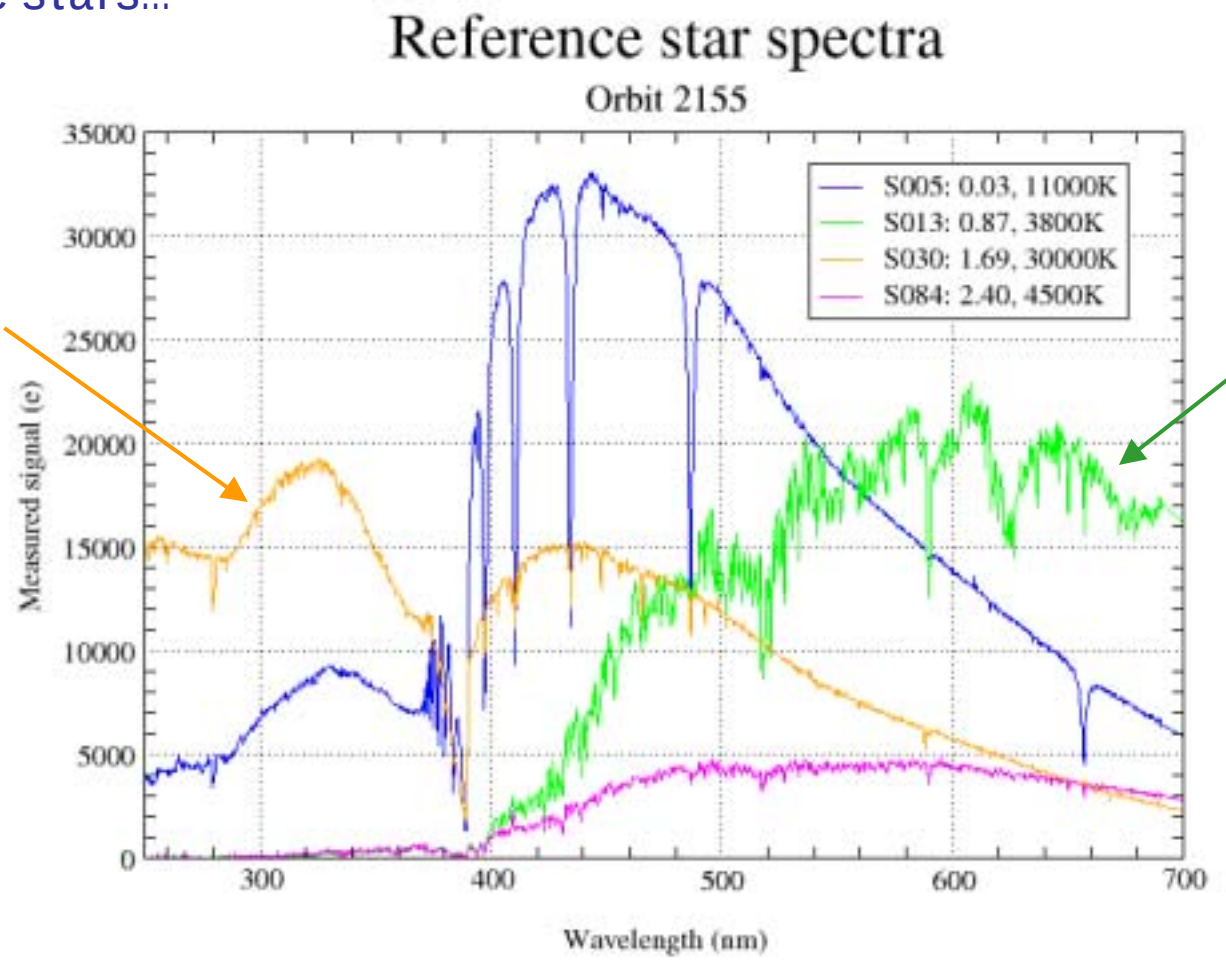
3 bands: upper, central,lower

Star signal is in the central band

Other bands are used for correction

3 spectra every 0.5 s

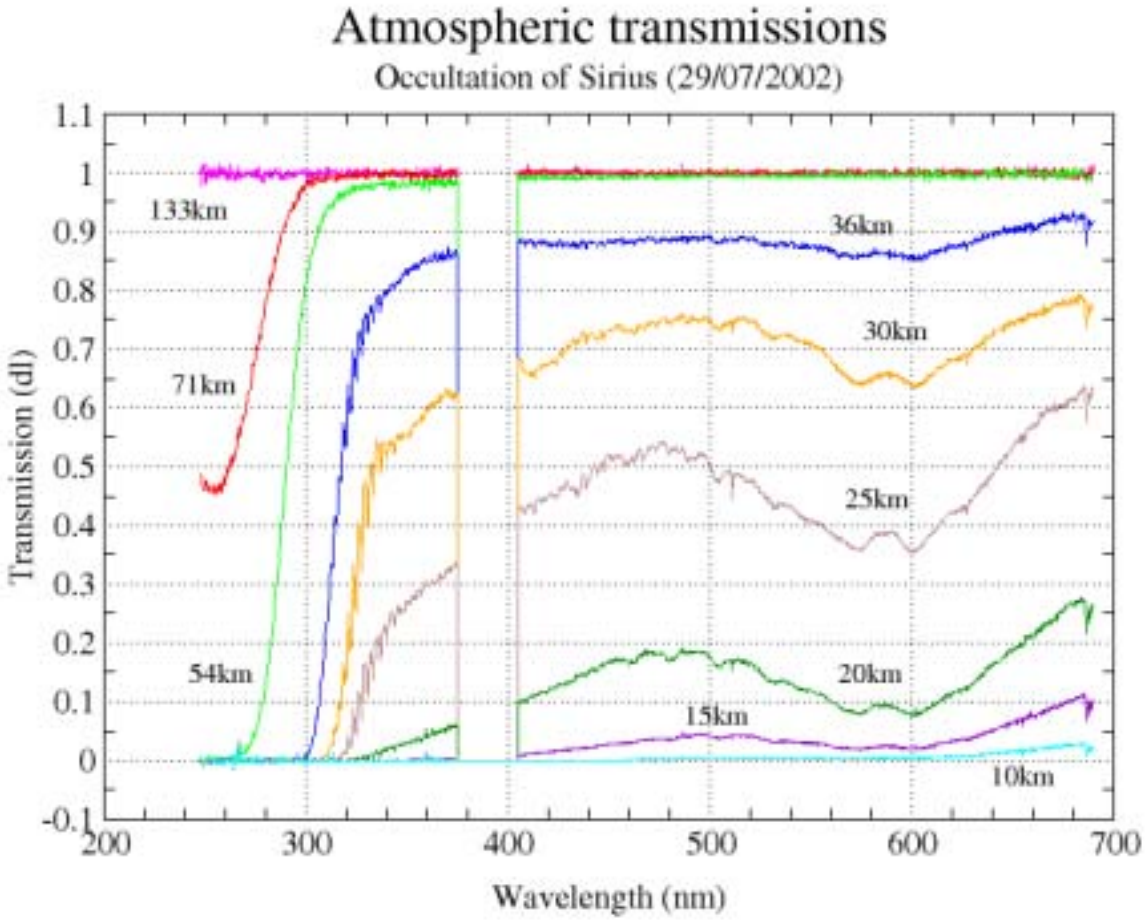
Some stars…



Hot star

Cold star

Transmission spectra



Stellar occultation

$$I(\lambda, p) = I_0(\lambda) \cdot e^{-\sum_i \sigma_i(\lambda) \cdot N_i(p)}$$ *Intensity*

Level 1 processing

$$T(\lambda, p) = \frac{I(\lambda, p)}{I_0(\lambda)}$$ *Transmission*

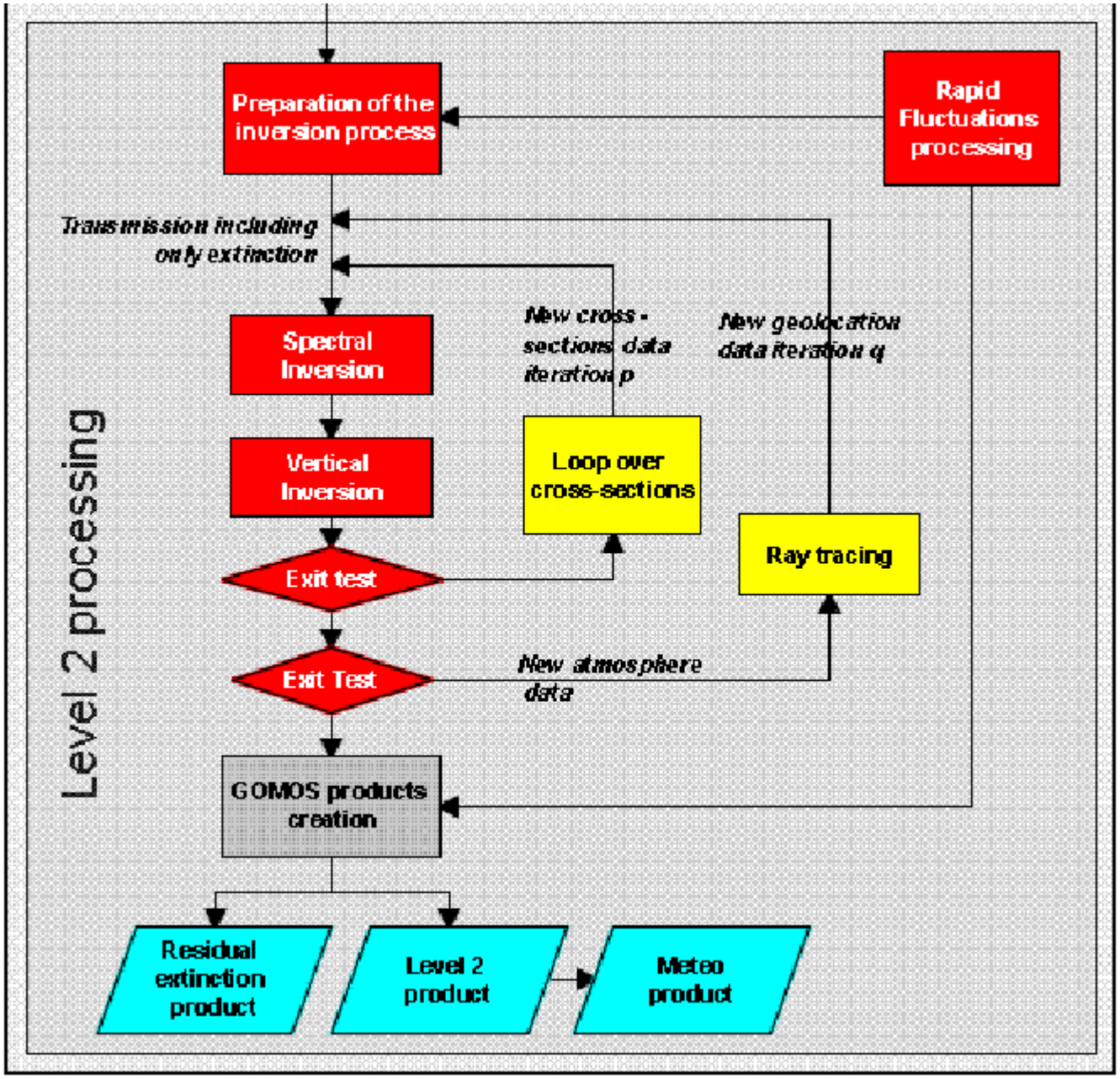
$$-\log\left(T(\lambda, p)\right) = \sum_i \left(\sigma_i(\lambda) \cdot N_i(p)\right)$$

Level 2 processing

Column Density

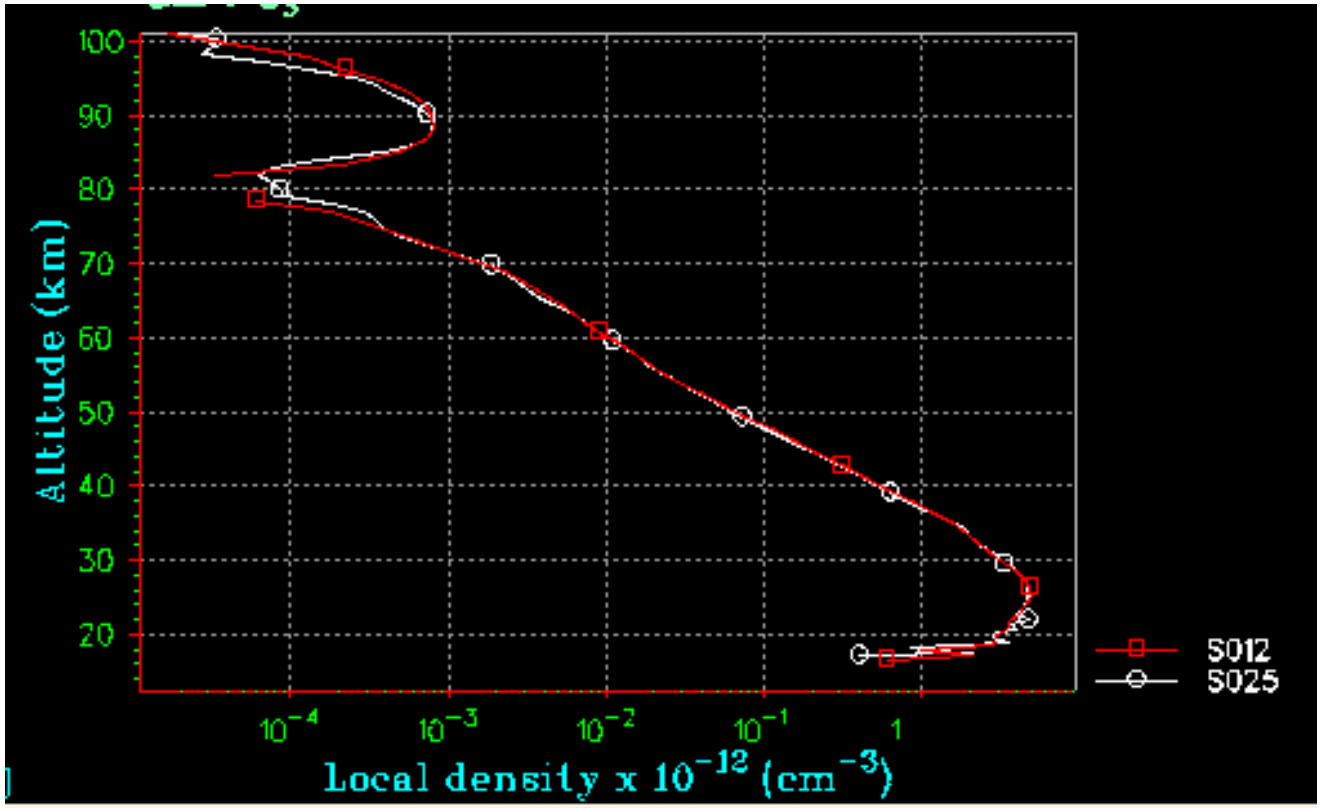
$$N_i(l) = \int_r n_i(l) \cdot dl$$

Local Density


Level 2 processing
Preparation of the inversion process
Rapid Fluctuations processing
Transmission including only extinction
Spectral Inversion
Vertical Inversion
Exit test
Exit Test
New cross - sections data iteration p
Loop over cross-sections
New geolocation data iteration q
Ray tracing
New atmosphere data
GOMOS products creation
Residual extinction product
Level 2 product
Meteo product

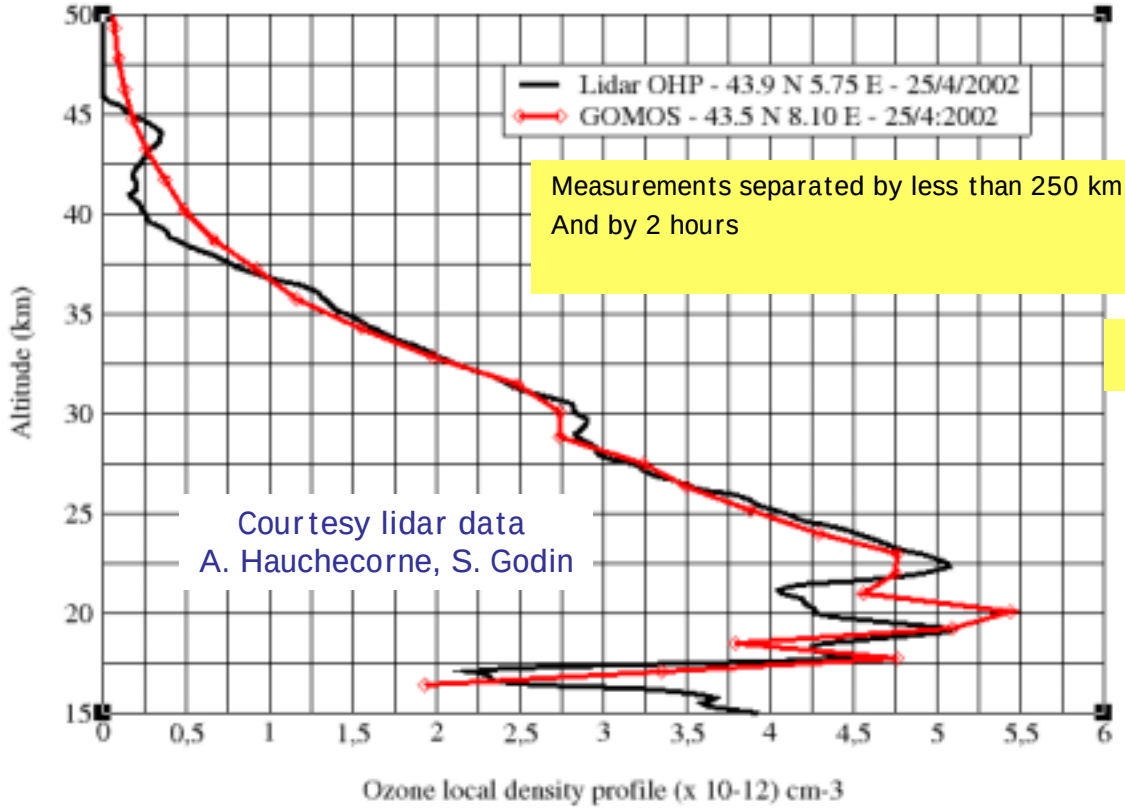
First GOMOS-GOMOS Coïncidence – Nominal operational processing

- Occultations of Star 12 (Orbit 690) and 25 (Orbit 691)
- Geolocation interdistance is less than 25 km and time difference is less than 2 hours



Early start of the validation phase

- First GOMOS-external ozone local (lidar – OHP) profile comparison

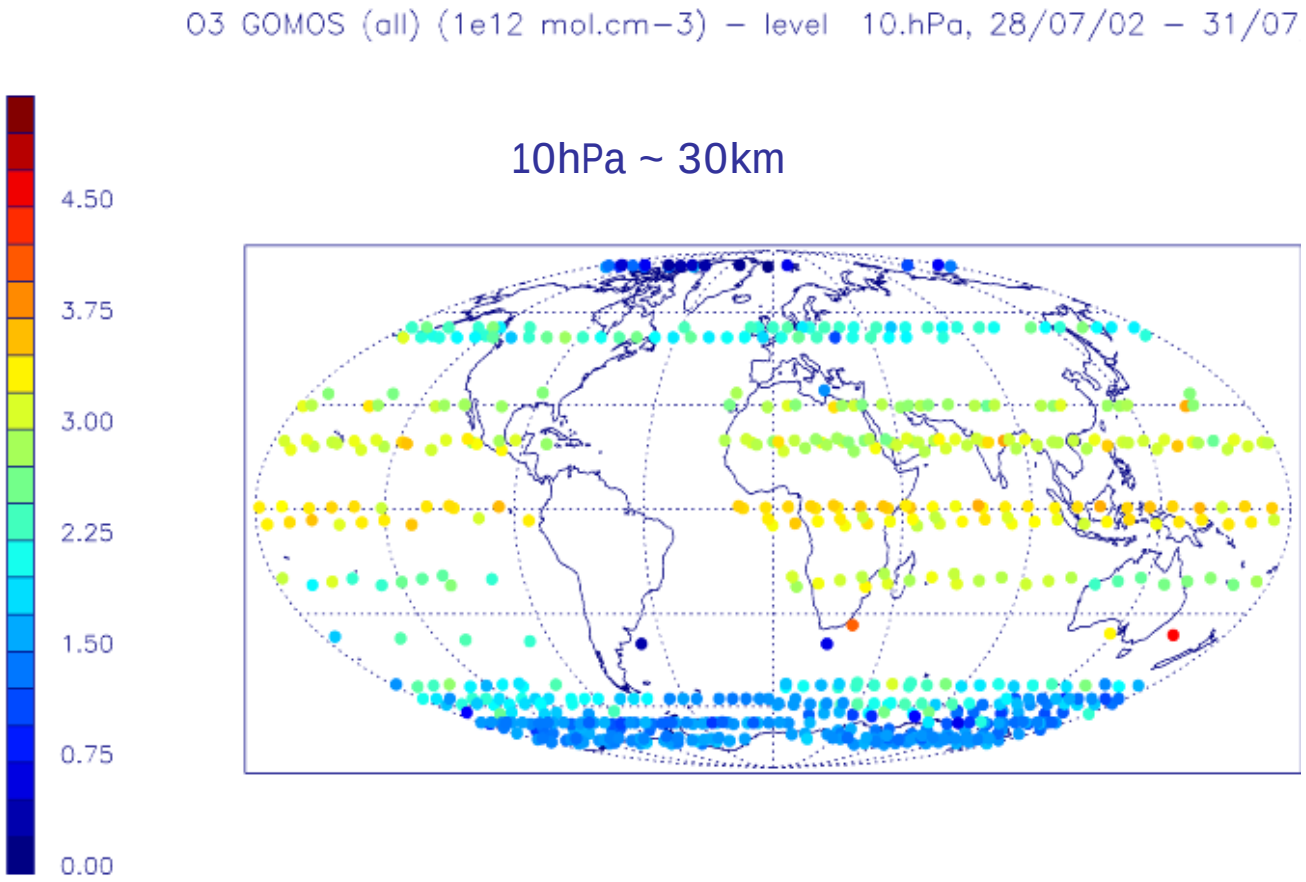


Measurements separated by less than 250 km
And by 2 hours

Courtesy lidar data
A. Hauchecorne, S. Godin

Mv=2.36 , T=28000K

R00799/S081



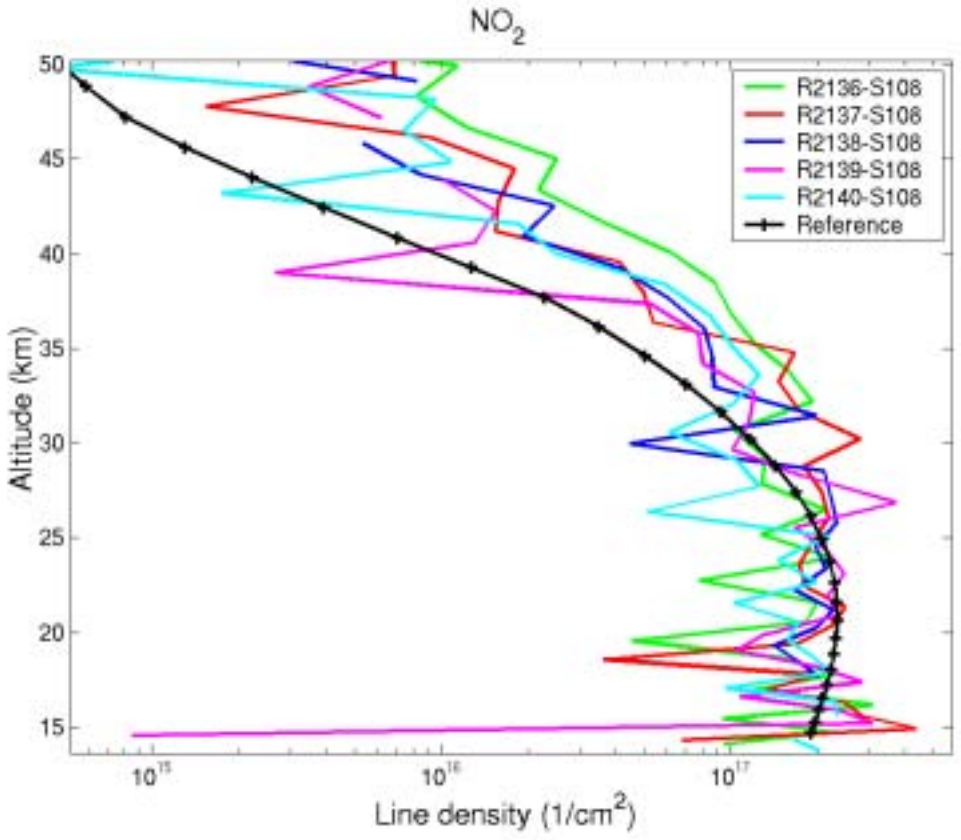
10hPa ~ 30km

1.e12 mol.cm-3

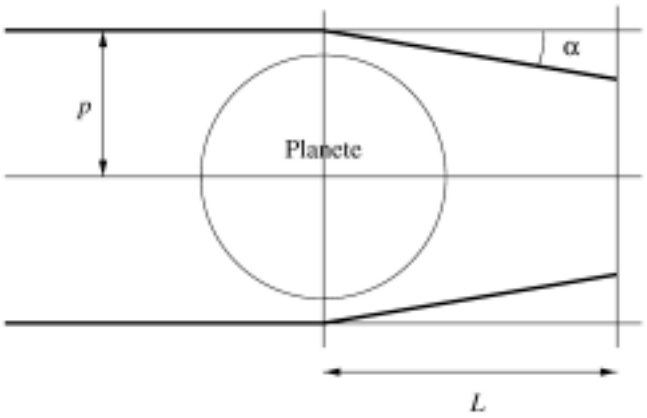
NO2 line densities

Ozone line densities (typical star Alpha Col, Mv = 2.65 T = 15000)

Occultations around latitude -53 deg (28.7 - 29.7 2002)



Dilution et scintillation….



$$y = p + \alpha L$$

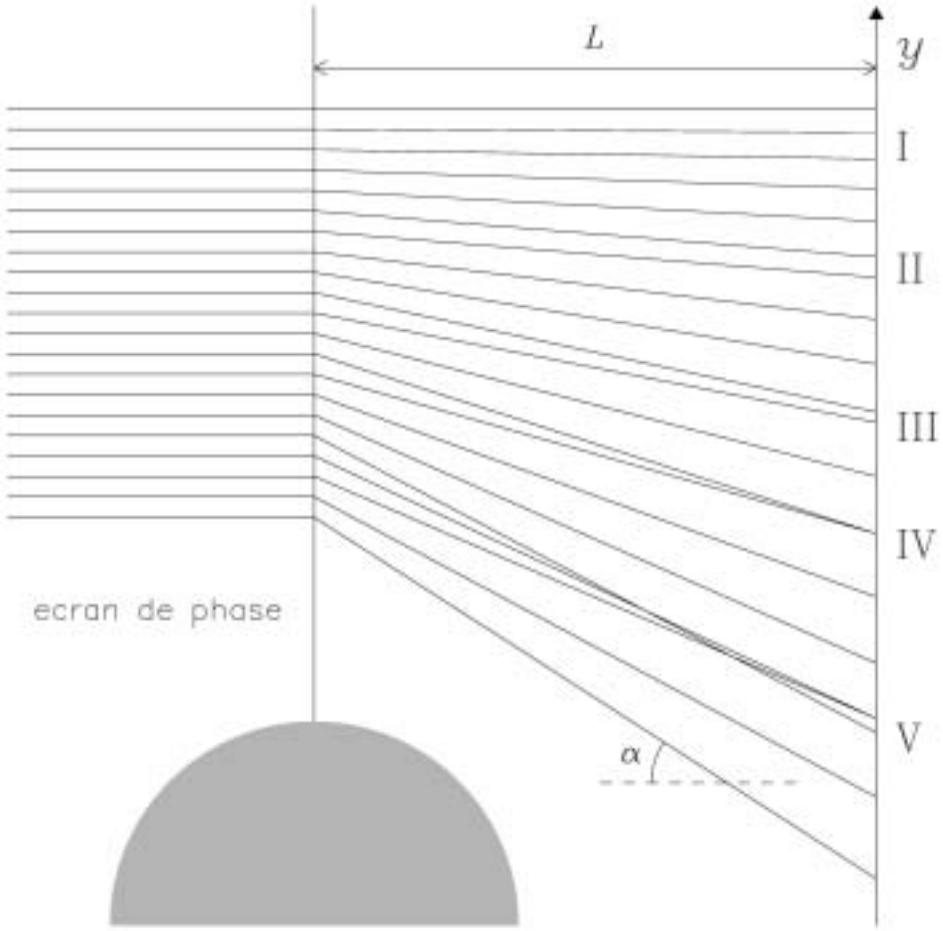
$$S = \pi(p + \alpha L)^2 \qquad S_0 = \pi p^2$$

$$dS_0 = 2\pi p\, dp$$

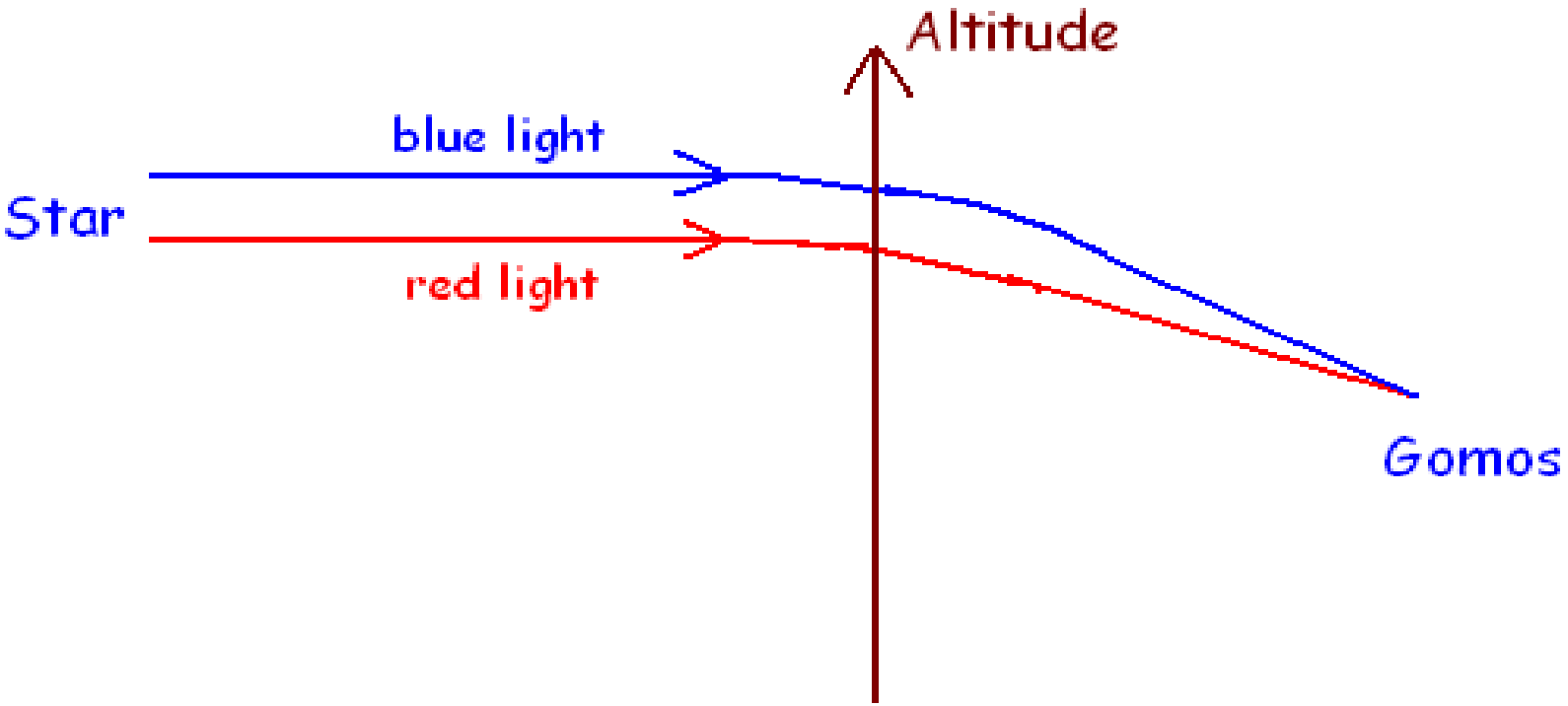
$$dS = 2\pi(p + \alpha L)\left(1 + L\frac{d\alpha}{dp}\right) dp$$

L'intensité q est donnée par le rapport des surfaces dS_0/dS :

$$q = \frac{1}{1 + \alpha\frac{L}{p}} \frac{1}{1 + L\frac{d\alpha}{dp}}$$

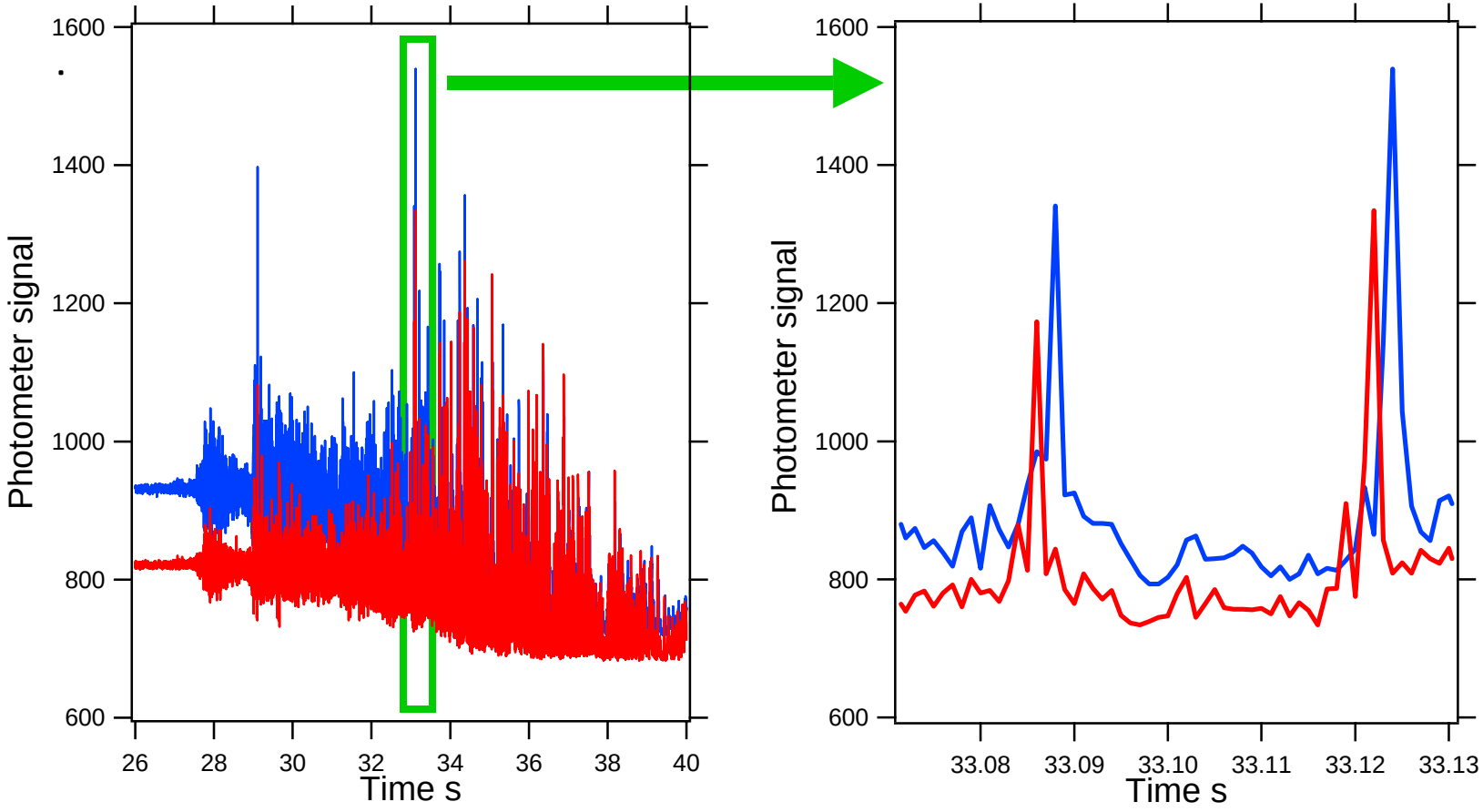


Chromatic refraction



Time delay between the red and the blue photometer

R02010/S009 – 19 July 2002



Algorithm High Resolution Temperature Profile

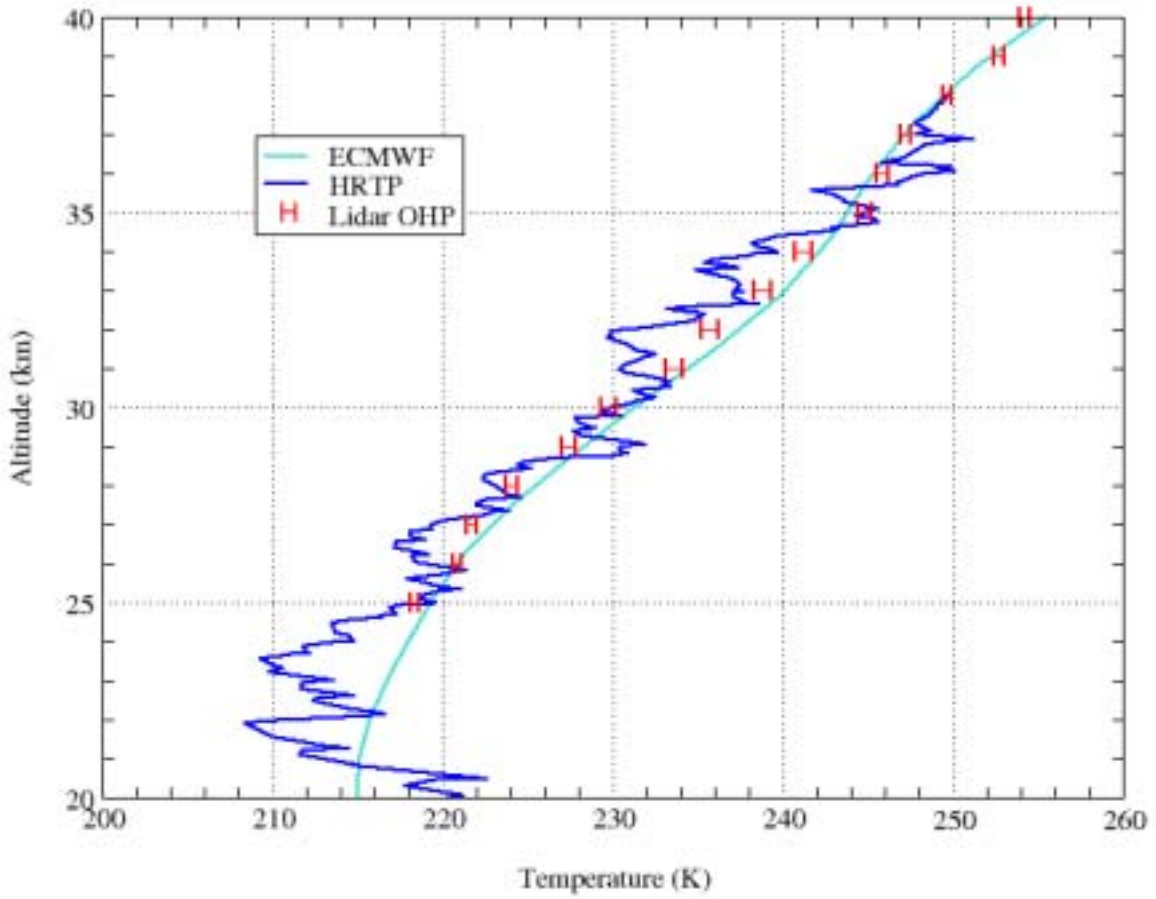
From time delay between blue and red photometer scintillation signals :

→ angle of refraction vs impact parameter

→ vertical profile of index of refraction

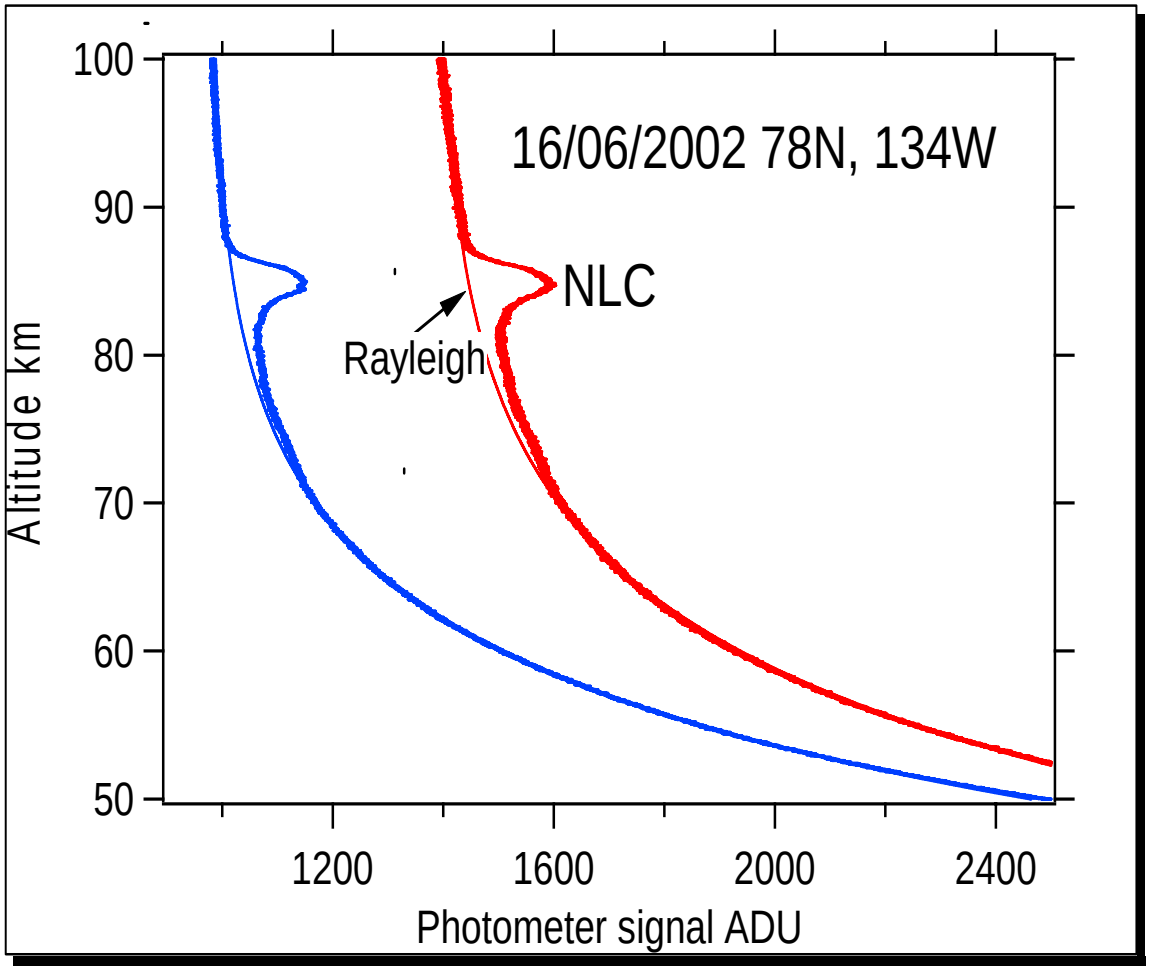
→ vertical profile of atmospheric P, T and ρ at 200 m vertical resolution

25 April 2002
43.5 N, 8.1E
Star 81
(Mv=2.36 ; T=28000K)



Noctilucent clouds

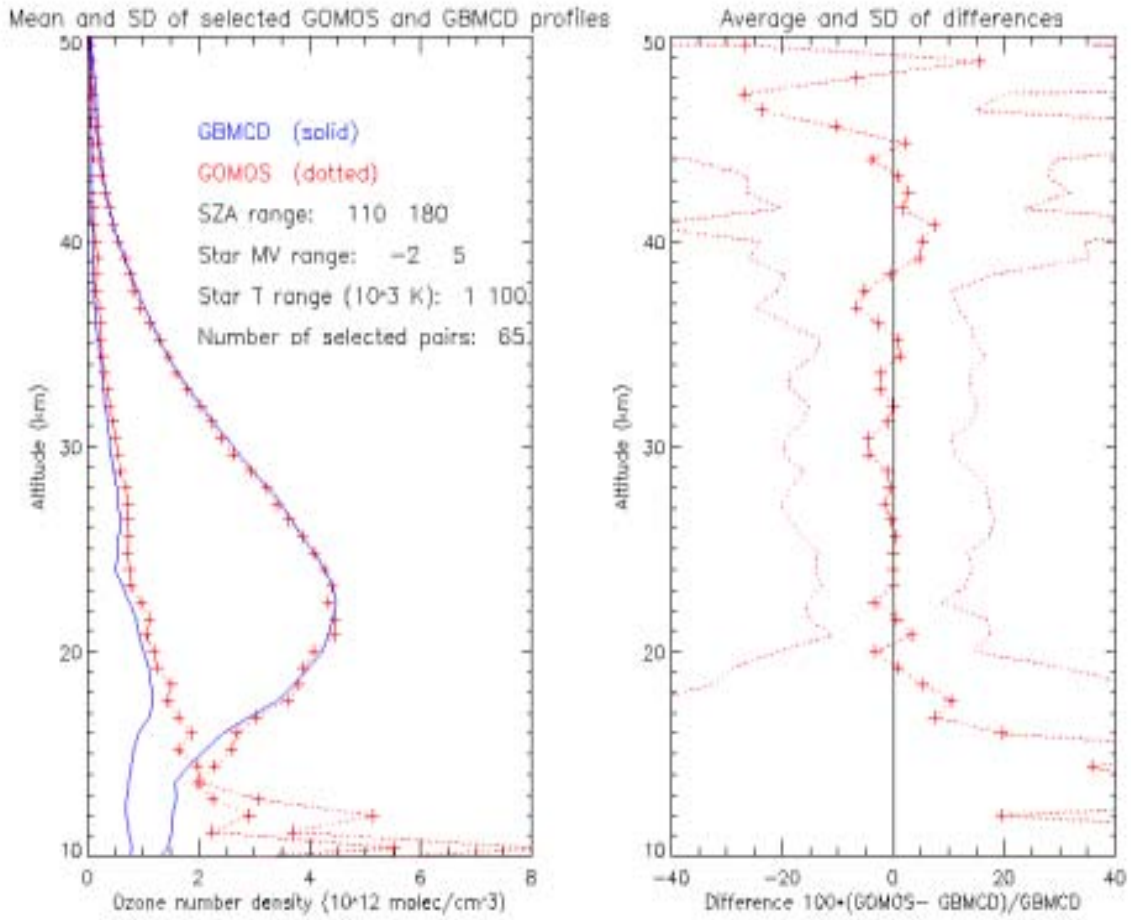
- Noctilucent clouds form in high latitude summer mesosphere
- Need very cold temperature + water vapour
- Potential indicators of global atmospheric changes
- Observed by GOMOS photometers and spectrometers



All GBM instruments

DARK

N = 65

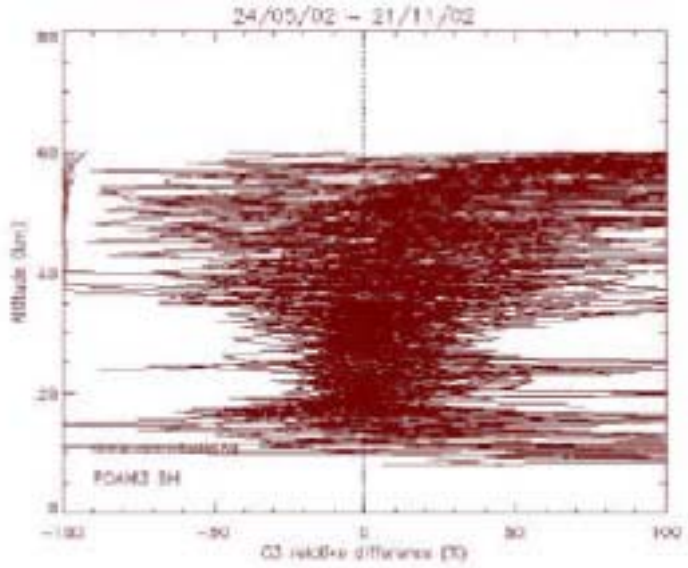


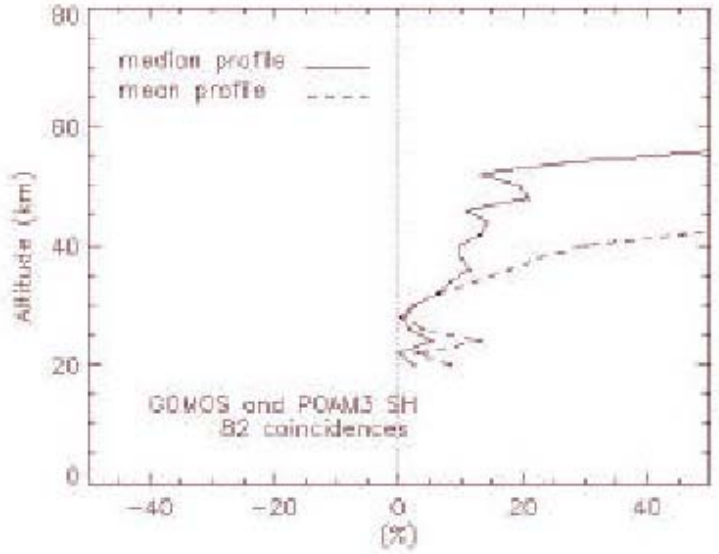
Conclusions vs all GBMCD instruments:

- **bright limb ozone profiles:**
  - only for bright (MV<1) stars and only above 30 km
  - GOMOS lower by 10 to 15% (30-50 km)

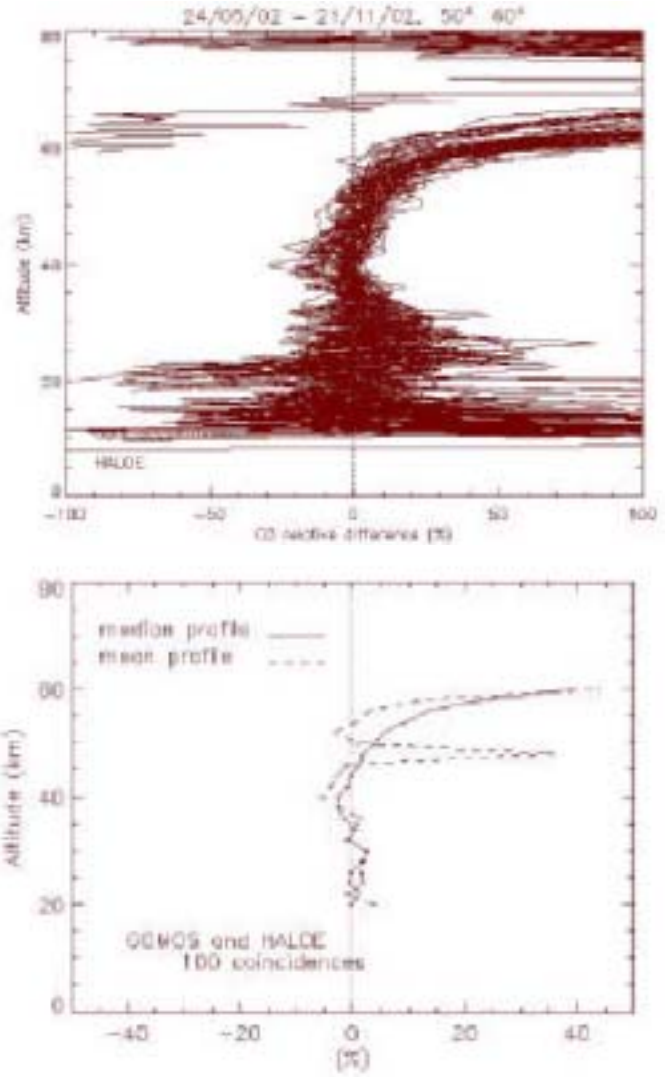
- **dark limb ozone profiles:**
  - star magnitude: no clear influence
  - below 18 km: poor results
  - 18-45 km: bias 5 to 10% (all stars)
  - 45-65 km :
    - cold stars: poor results
    - hot stars: bias within 20%, significant non-random bias suggests possibility for improvement

O_3 GOMOS/POAM

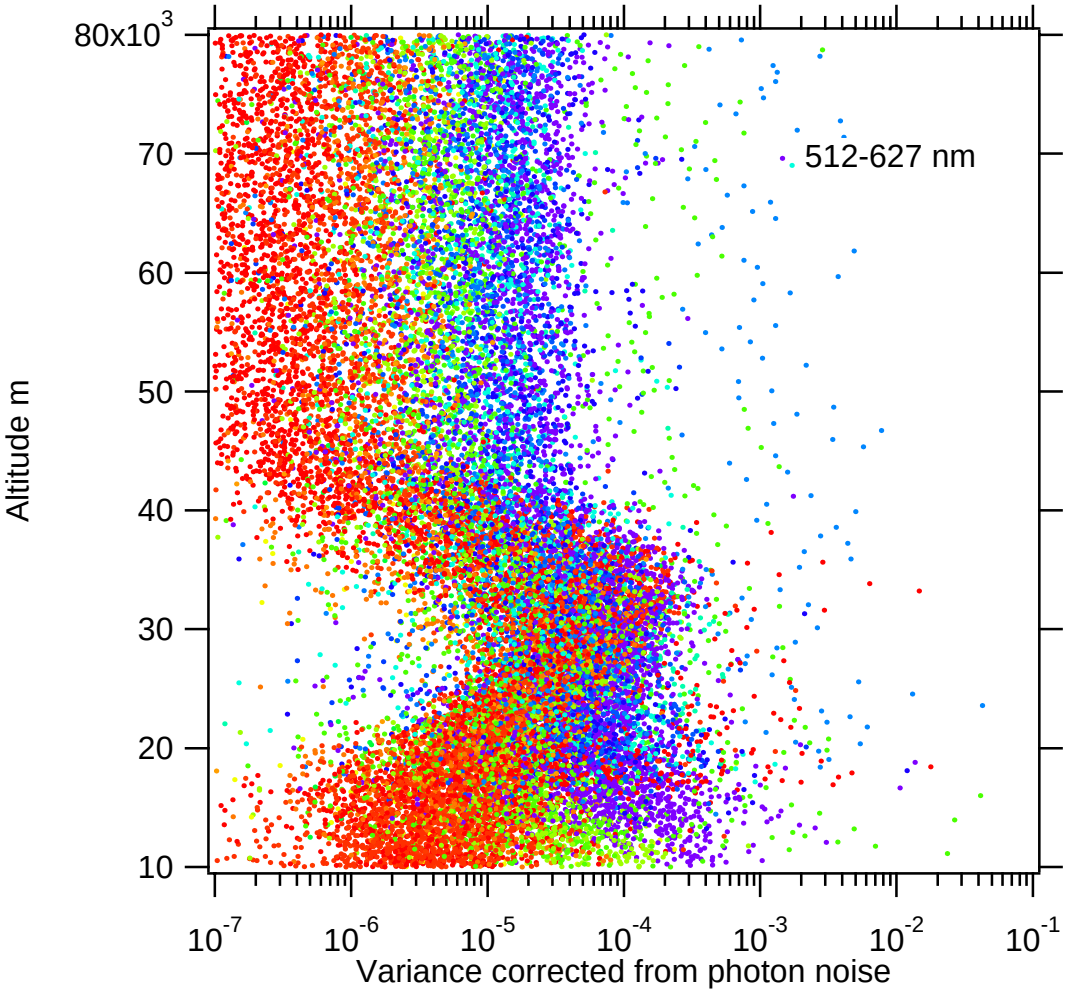




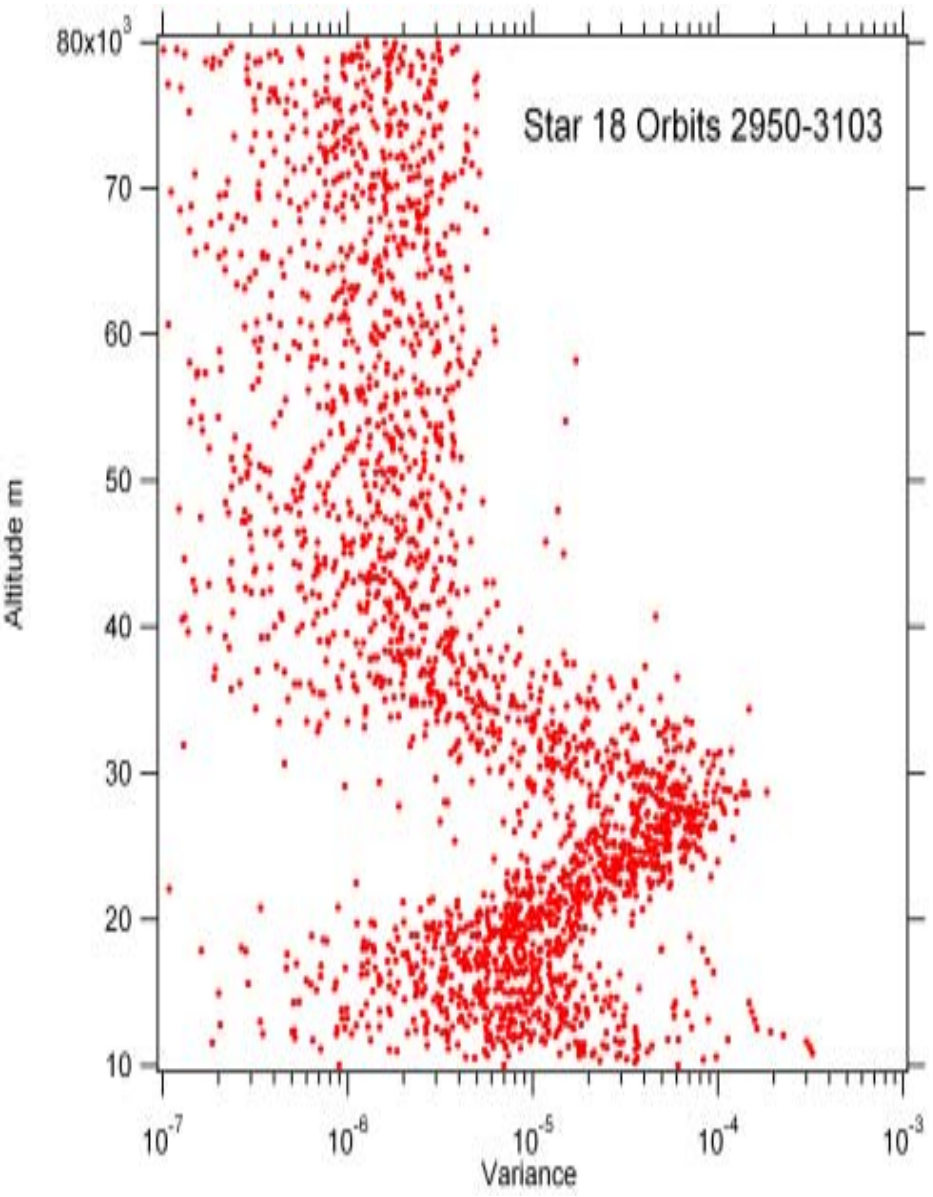
O_3 GOMOS/HALOE

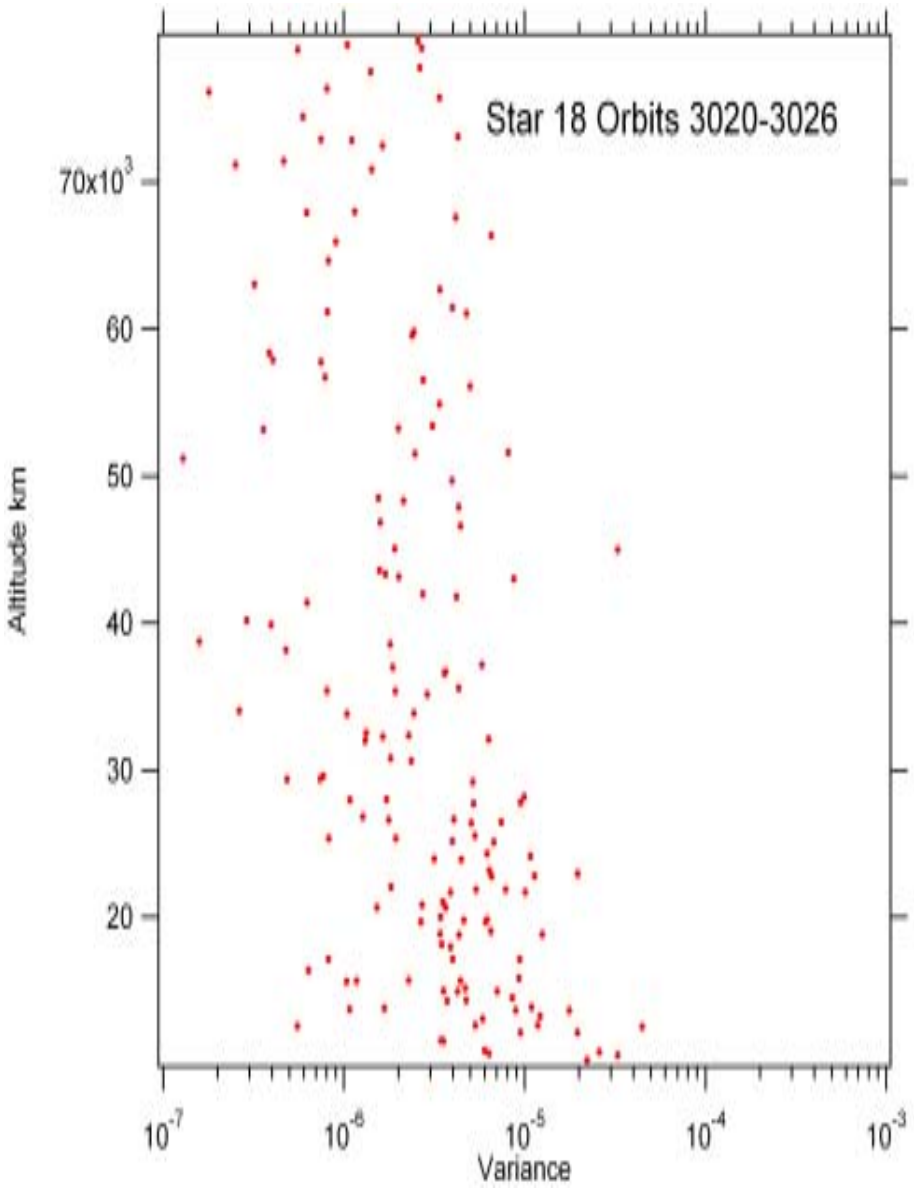


Variance for reference data set V4



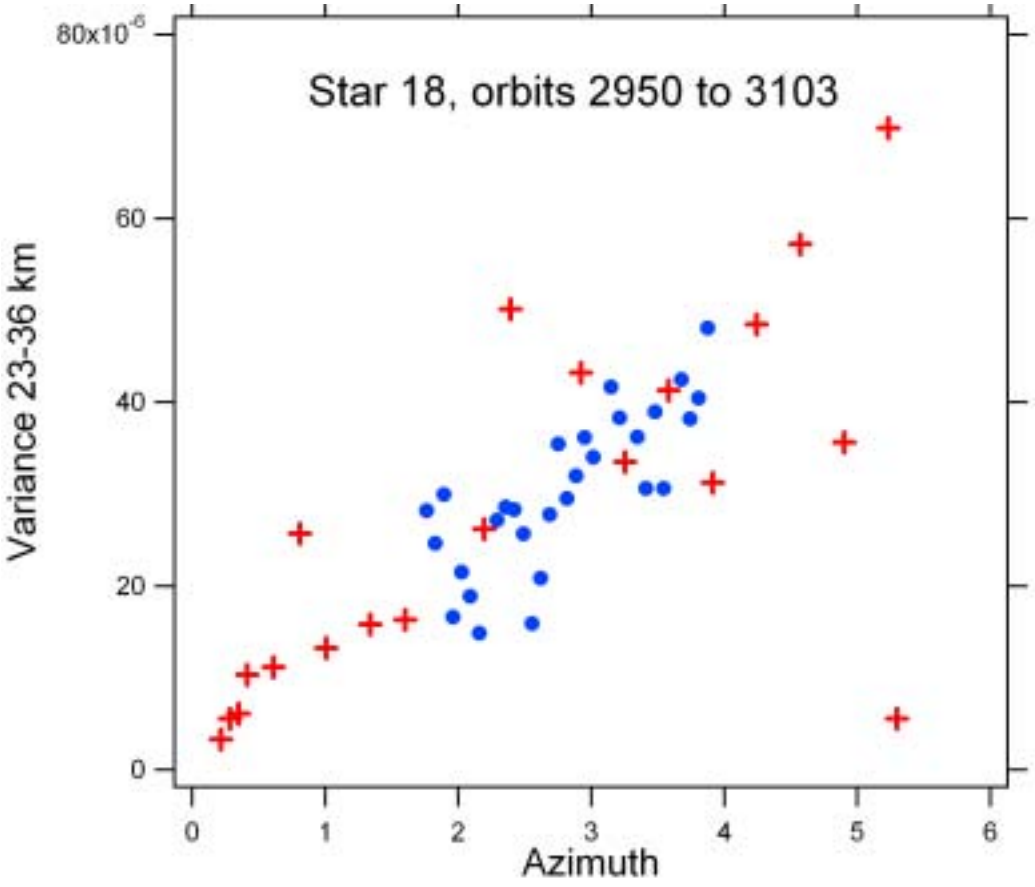
Variance of star 18, orbits 2950-3103



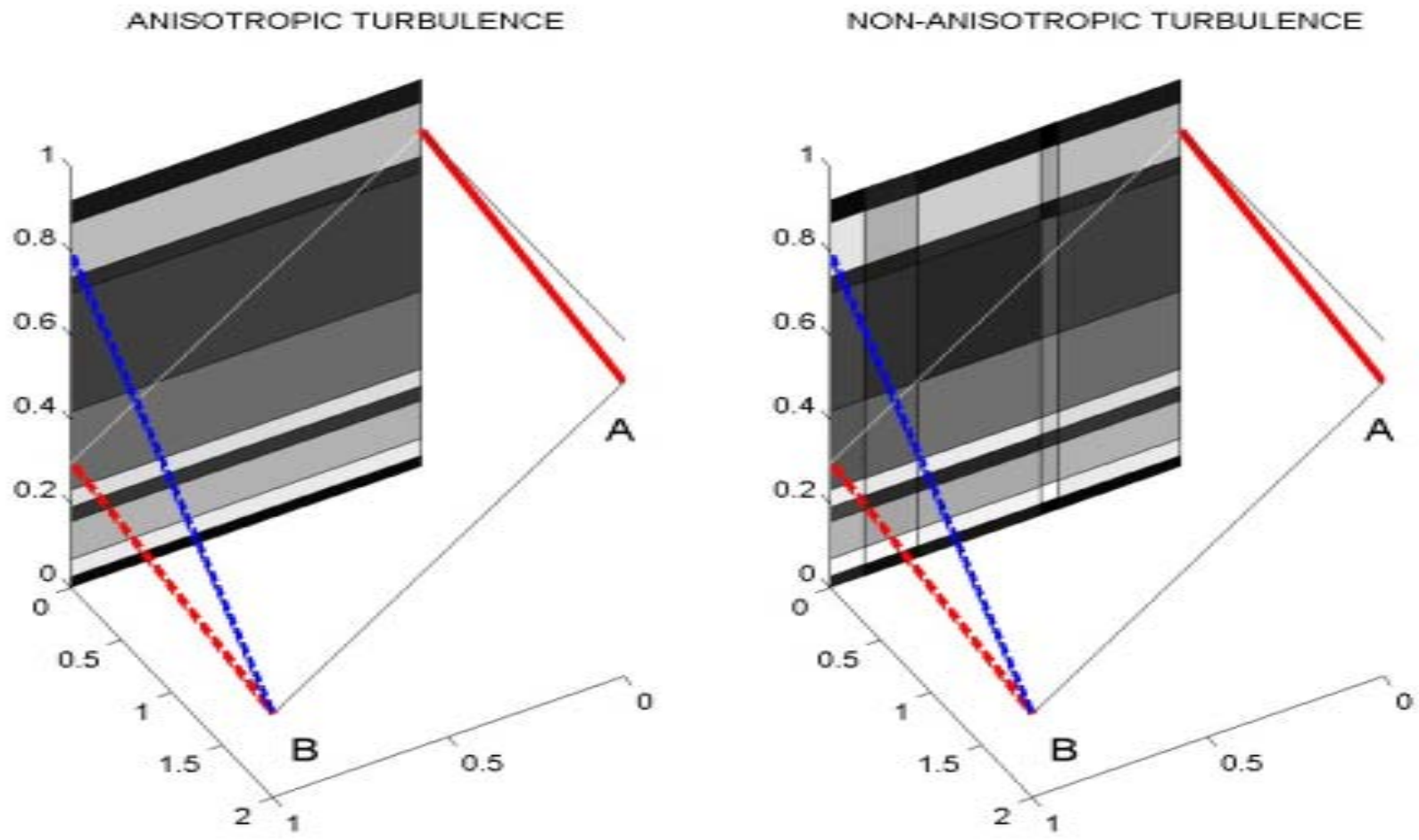


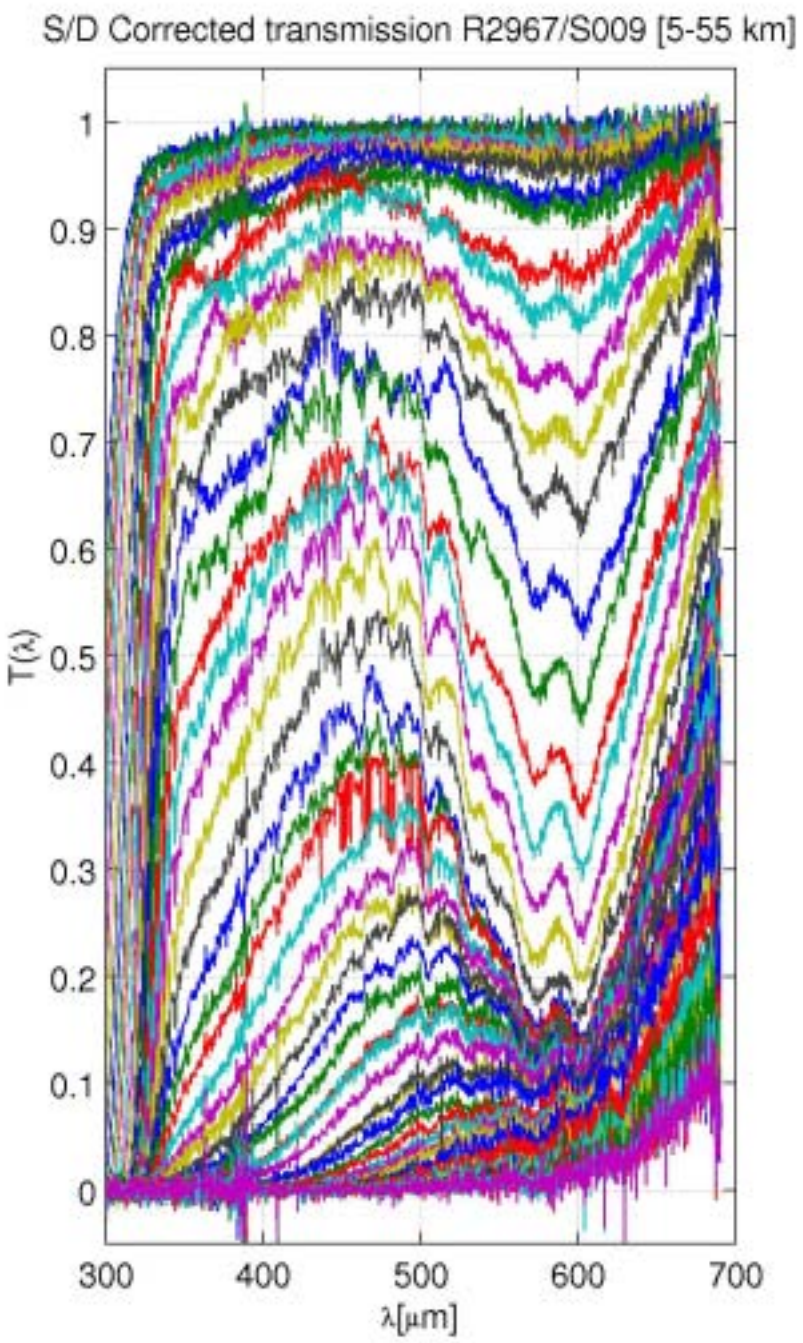
Variance vs azimuth, taking into account Earth rotation

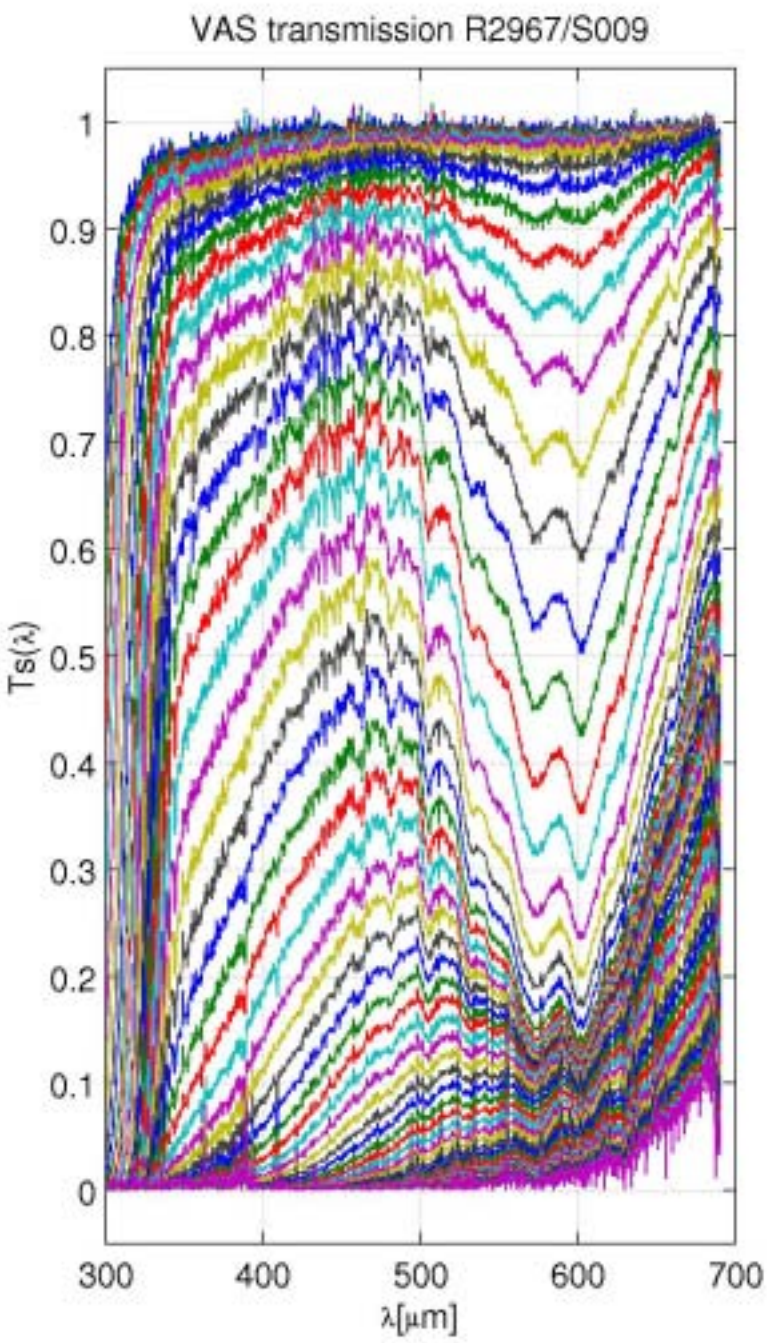
Negative azimuth mirrored to positive values

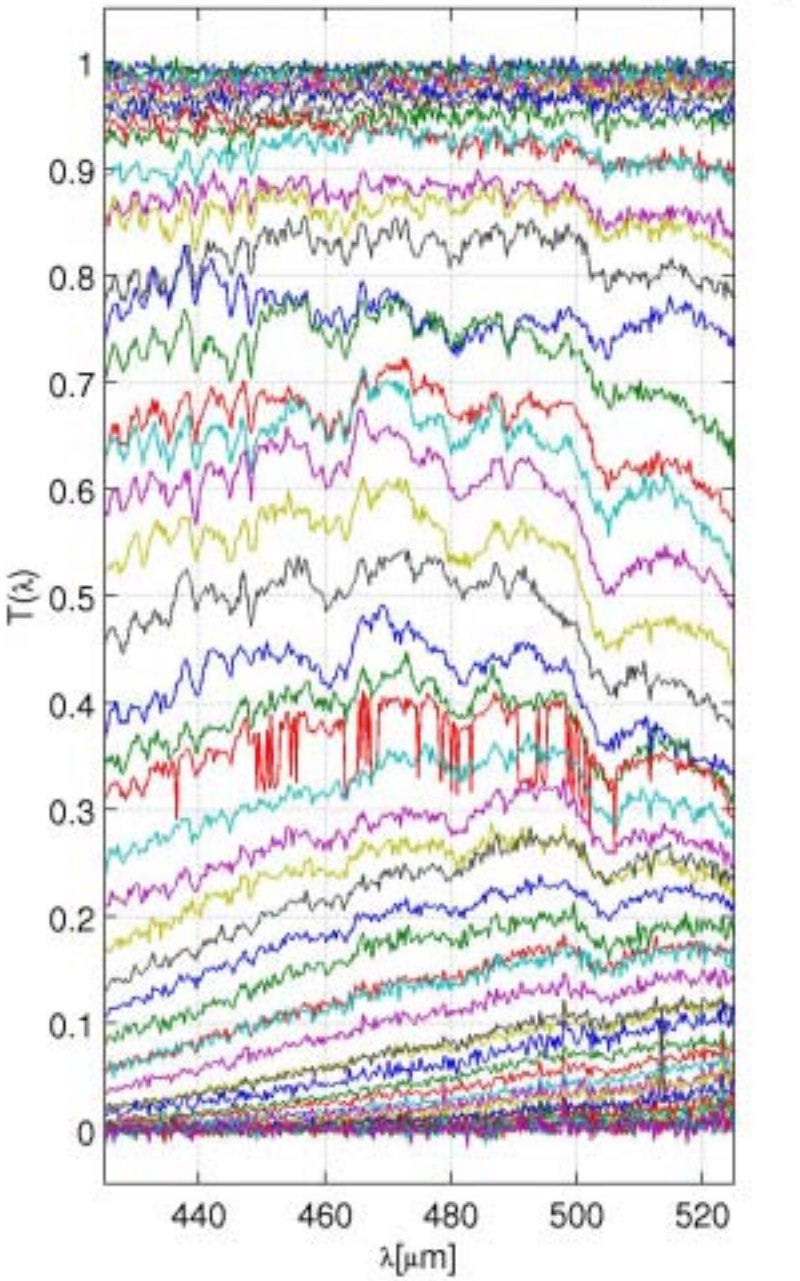


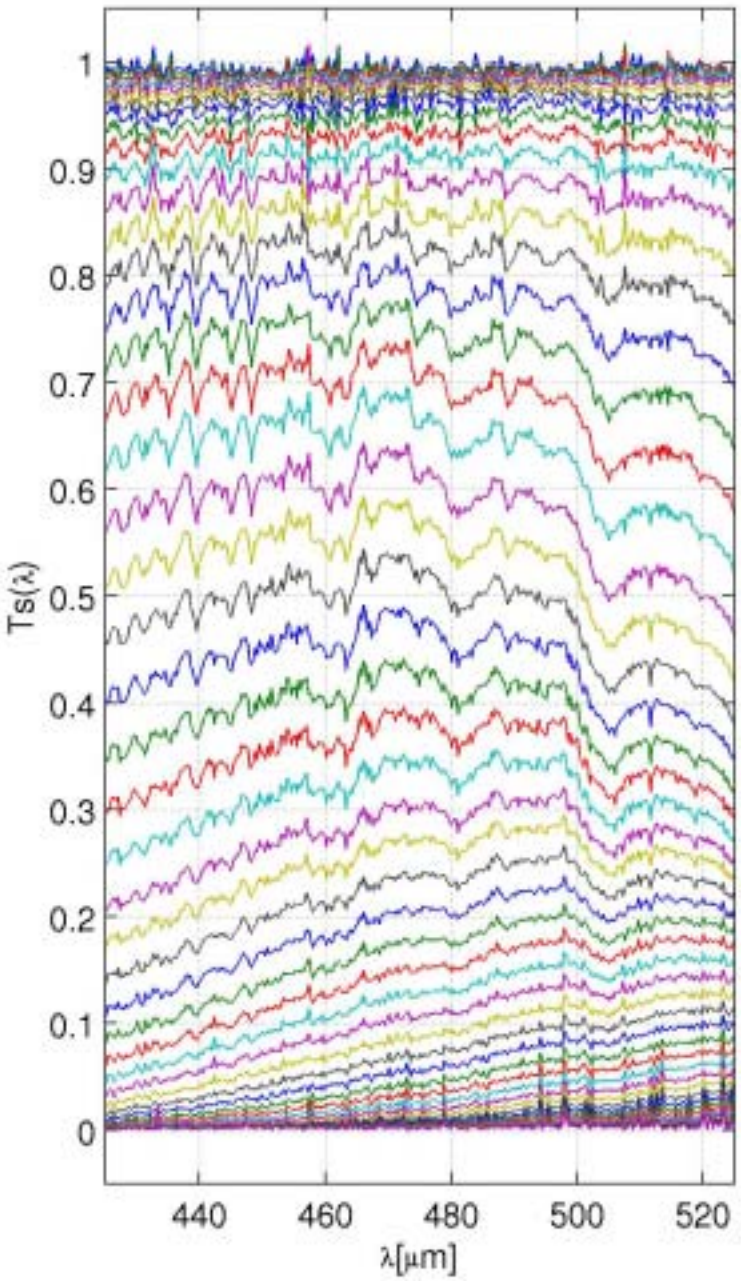
The GOMOS demodulation algorithm scintillation assumes a vertically stratified distribution of atmospheric density perturbations….

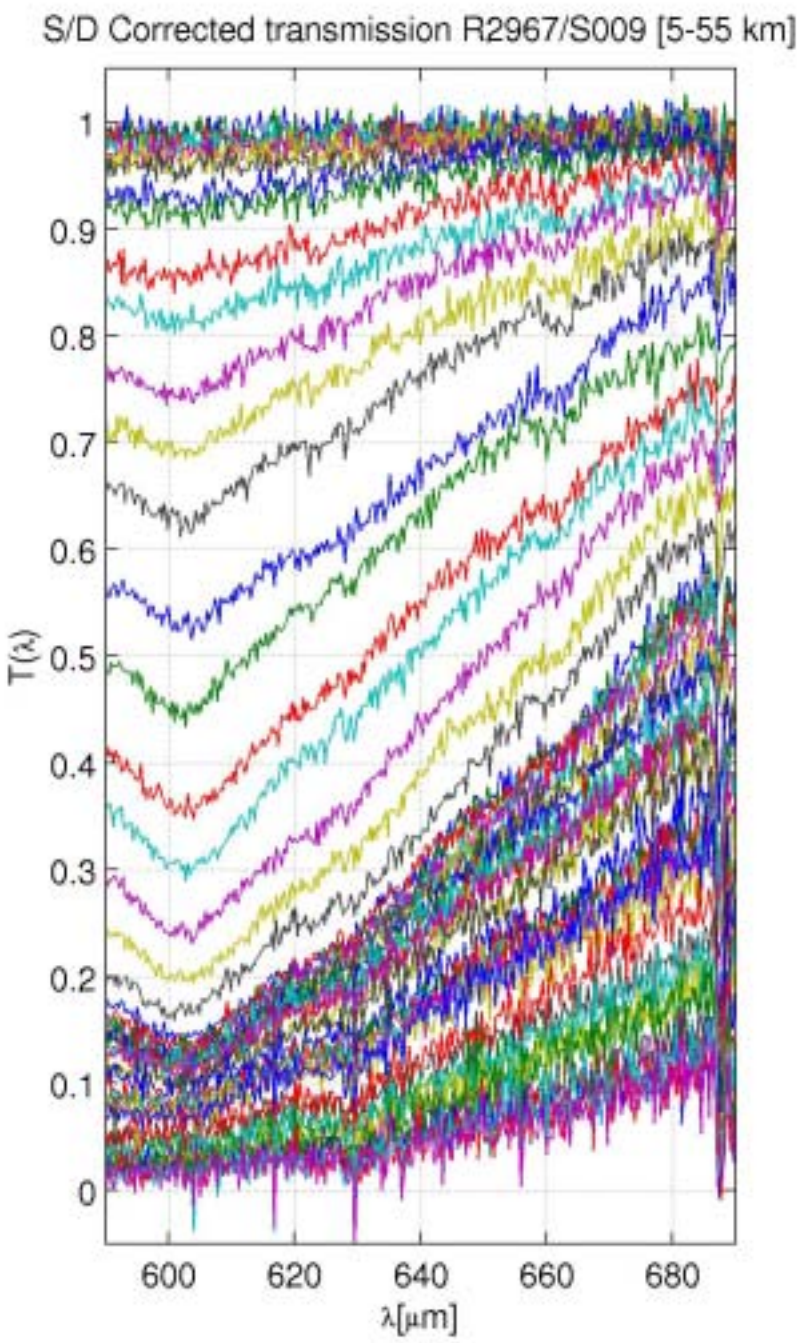


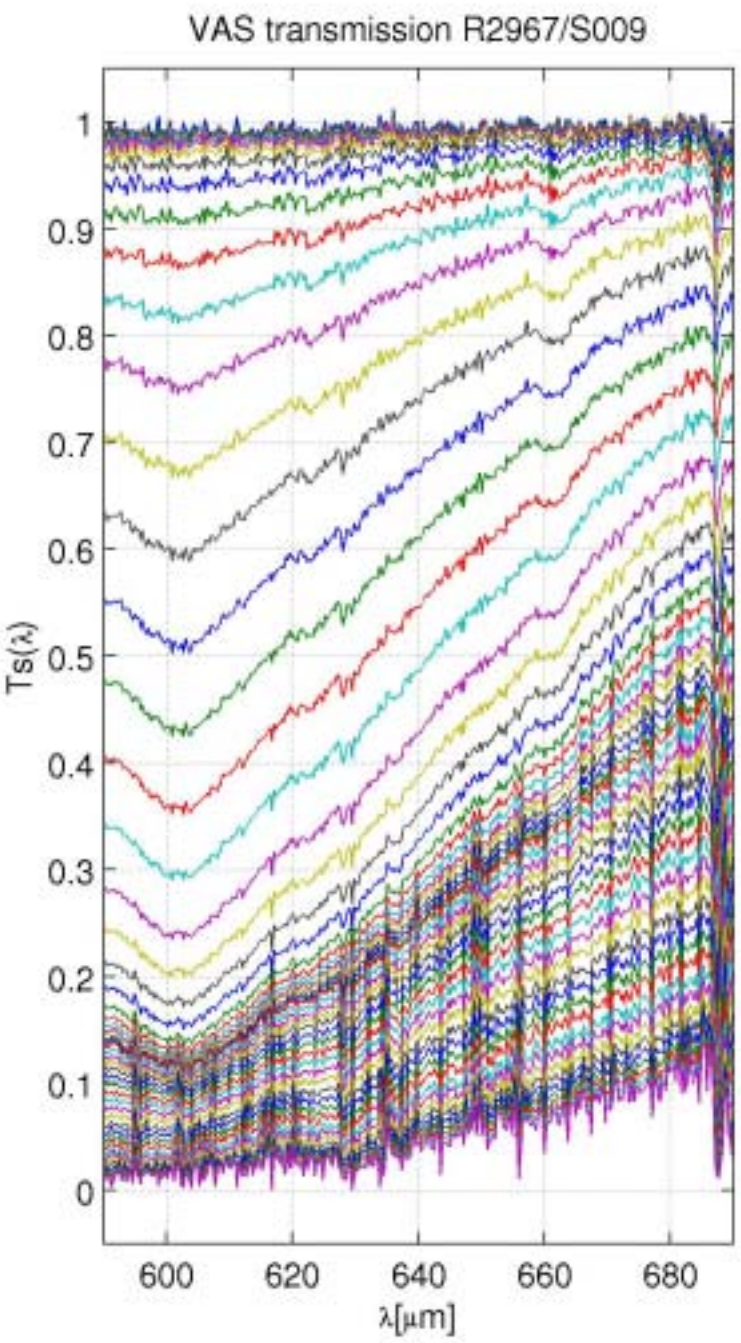

S/D Corrected transmission R2967/S009 [5-55 km]
T(λ)
λ[μm]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
300
400
500
600
700

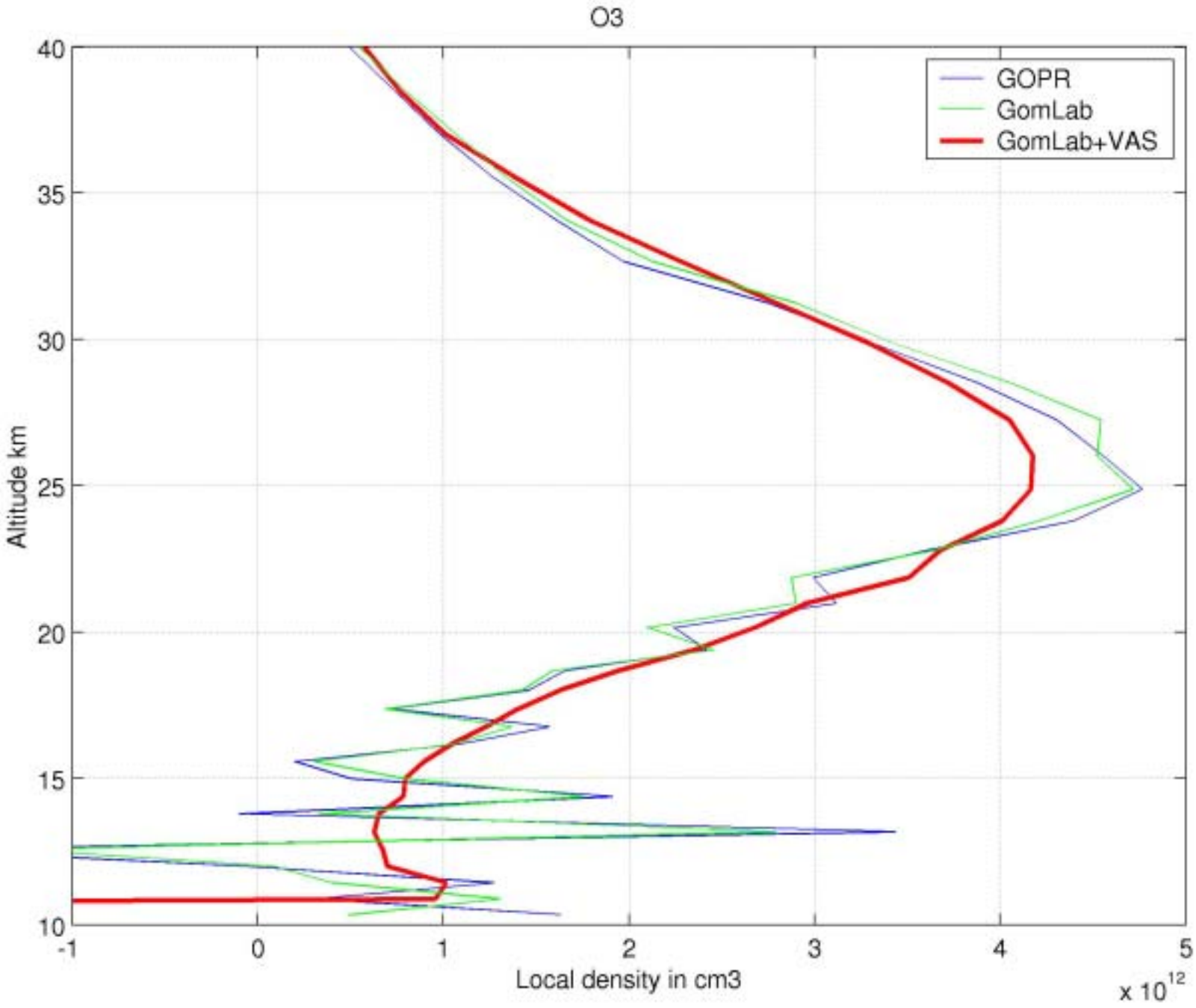

VAS transmission R2967/S009
Ts(λ)
λ[μm]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
300
400
500
600
700

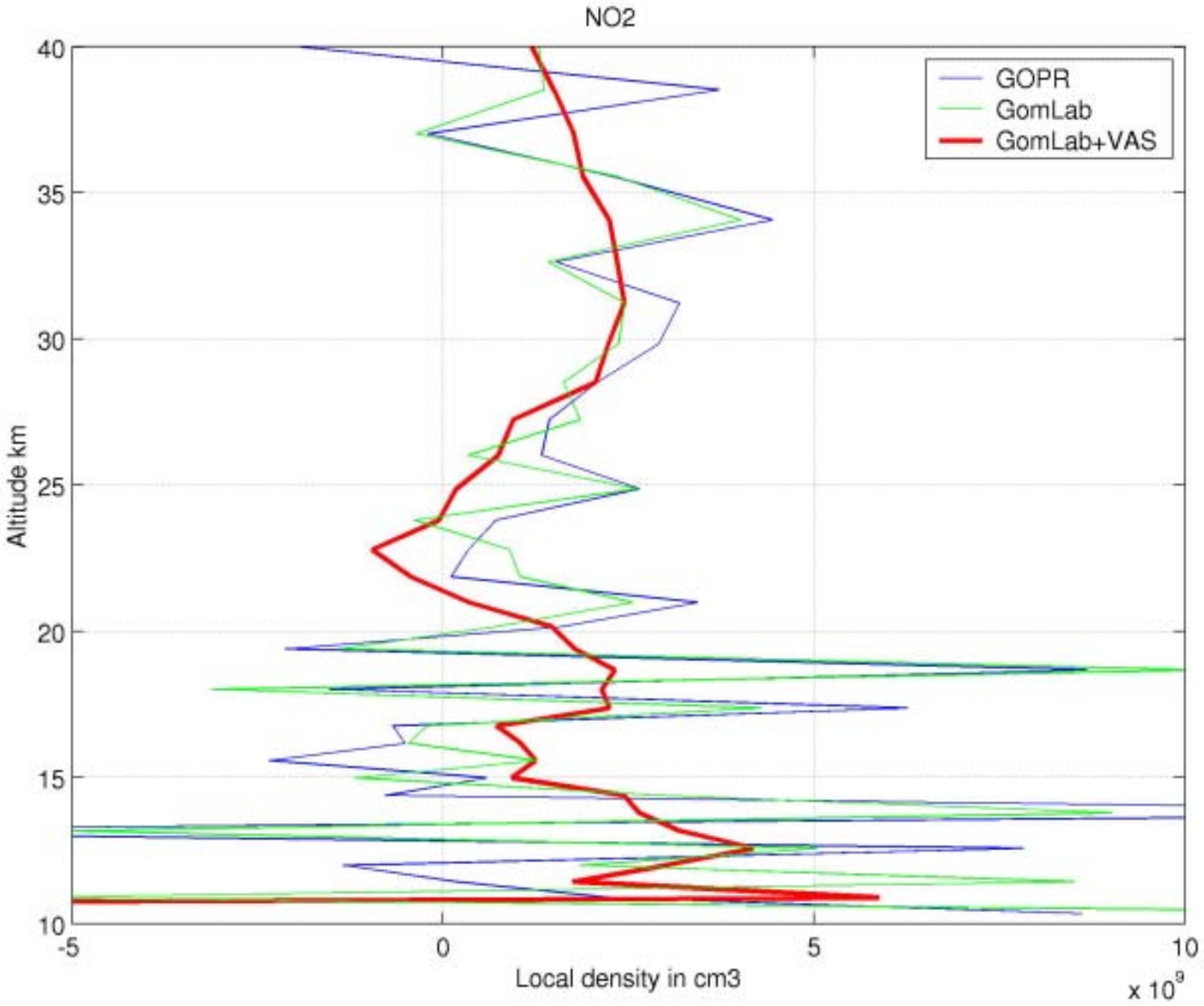

S/D Corrected transmission R2967/S009 [5-55 km]
T(λ)
λ[μm]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
440
460
480
500
520

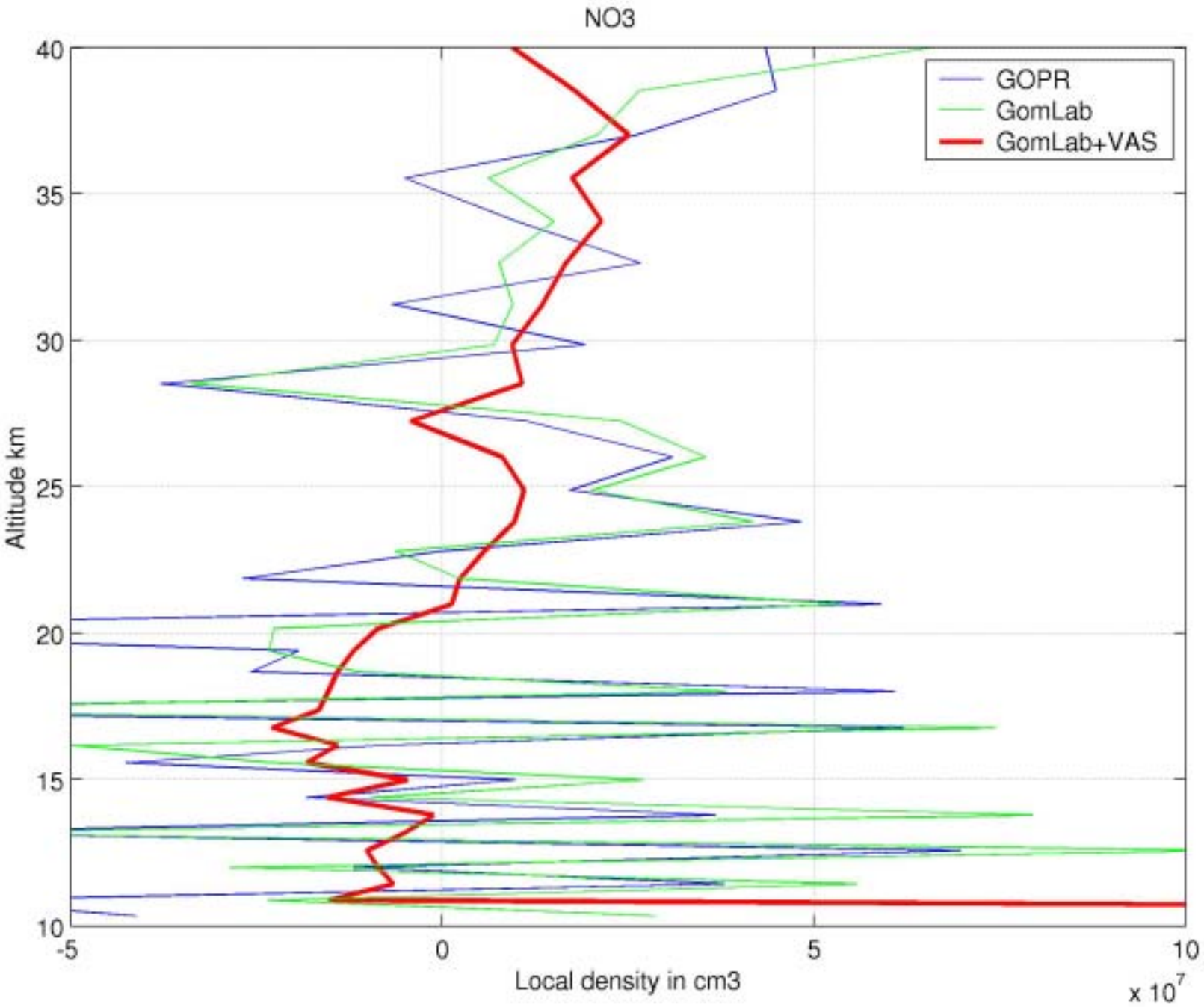

VAS transmission R2967/S009
Ts(λ)
λ[μm]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
440
460
480
500
520

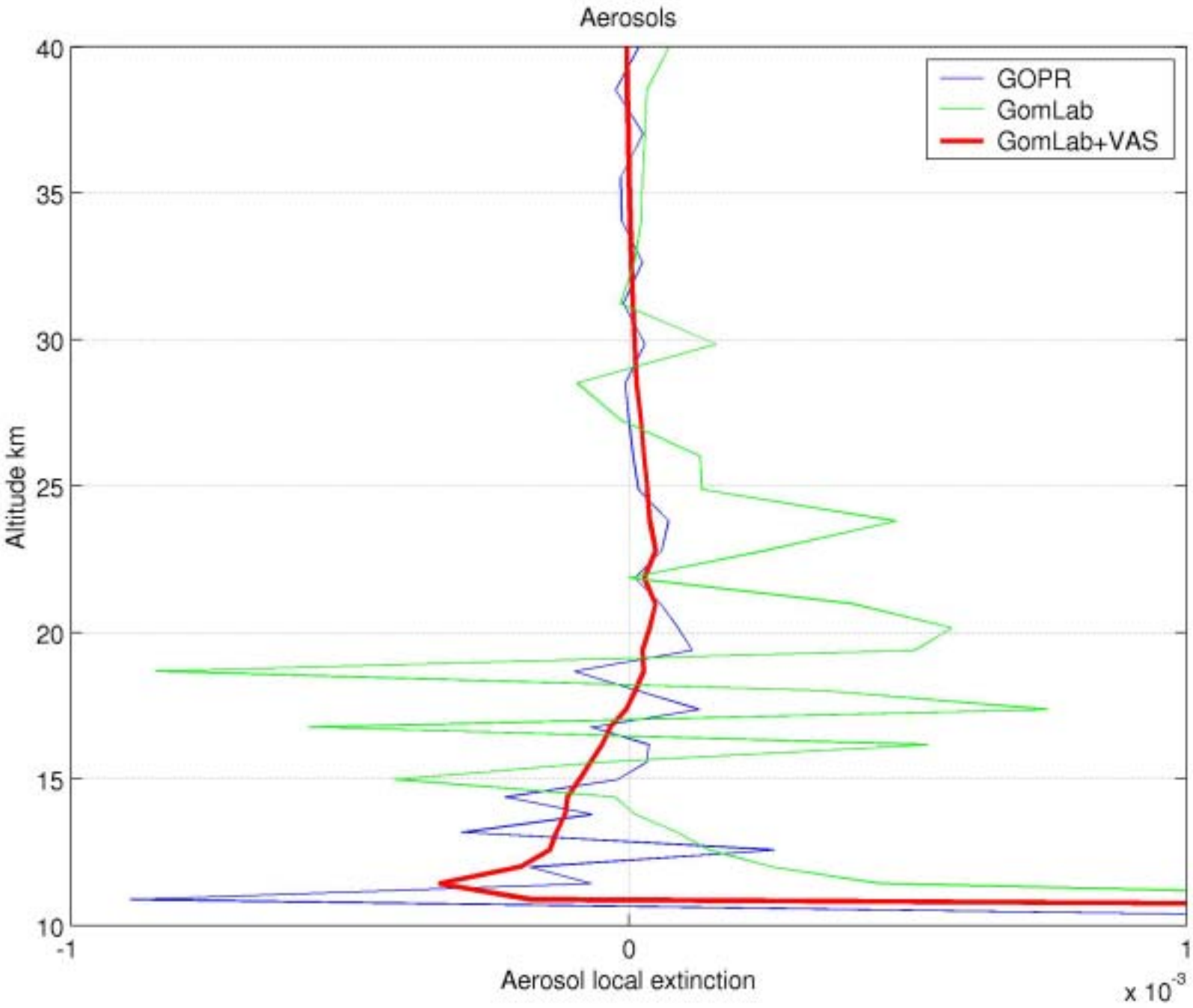

S/D Corrected transmission R2967/S009 [5-55 km]
T(λ)
λ[μm]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
600
620
640
660
680


VAS transmission R2967/S009
Ts(λ)
λ[μm]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
600
620
640
660
680


O3
GOPR
GomLab
GomLab+VAS
Altitude km
40
35
30
25
20
15
10
-1
0
1
2
3
4
5
Local density in cm3
x 10^12


NO2
GOPR
GomLab
GomLab+VAS
Altitude km
40
35
30
25
20
15
10
-5
0
5
10
Local density in cm3
x 10^9


NO3
GOPR
GomLab
GomLab+VAS
Altitude km
40
35
30
25
20
15
10
-5
0
5
10
Local density in cm3
x 10^7


Aerosols
GOPR
GomLab
GomLab+VAS
Altitude km
40
35
30
25
20
15
10
-1
0
1
Aerosol local extinction
x 10^-3

Conclusions

- GOMOS is working quite well…
- Meaningful comparisons already obtained
- Residual scintillation is the major difficulty to address in the retrieval algorithm
- Significative improvements are expected for O3 and minor constituents before end 2003