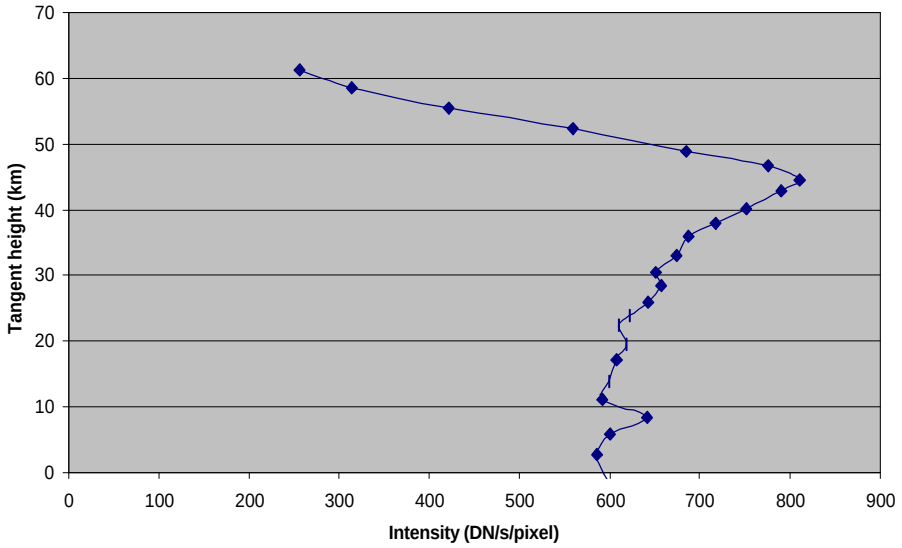
Attitude determination for limb-scanning satellite instruments: The “KNEE” at 305 nm

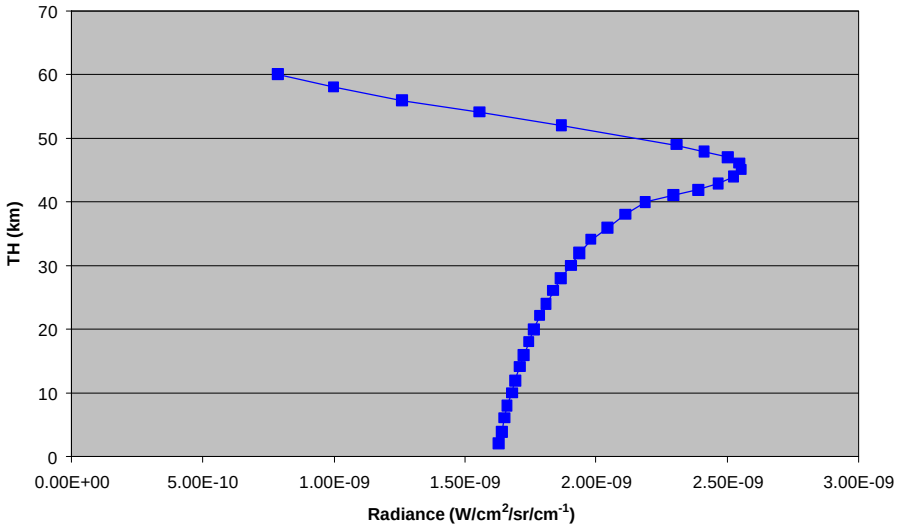
-pointing errors are the major limitation on the
in remote sensing of stratospheric trace gases from the limb scatter technique

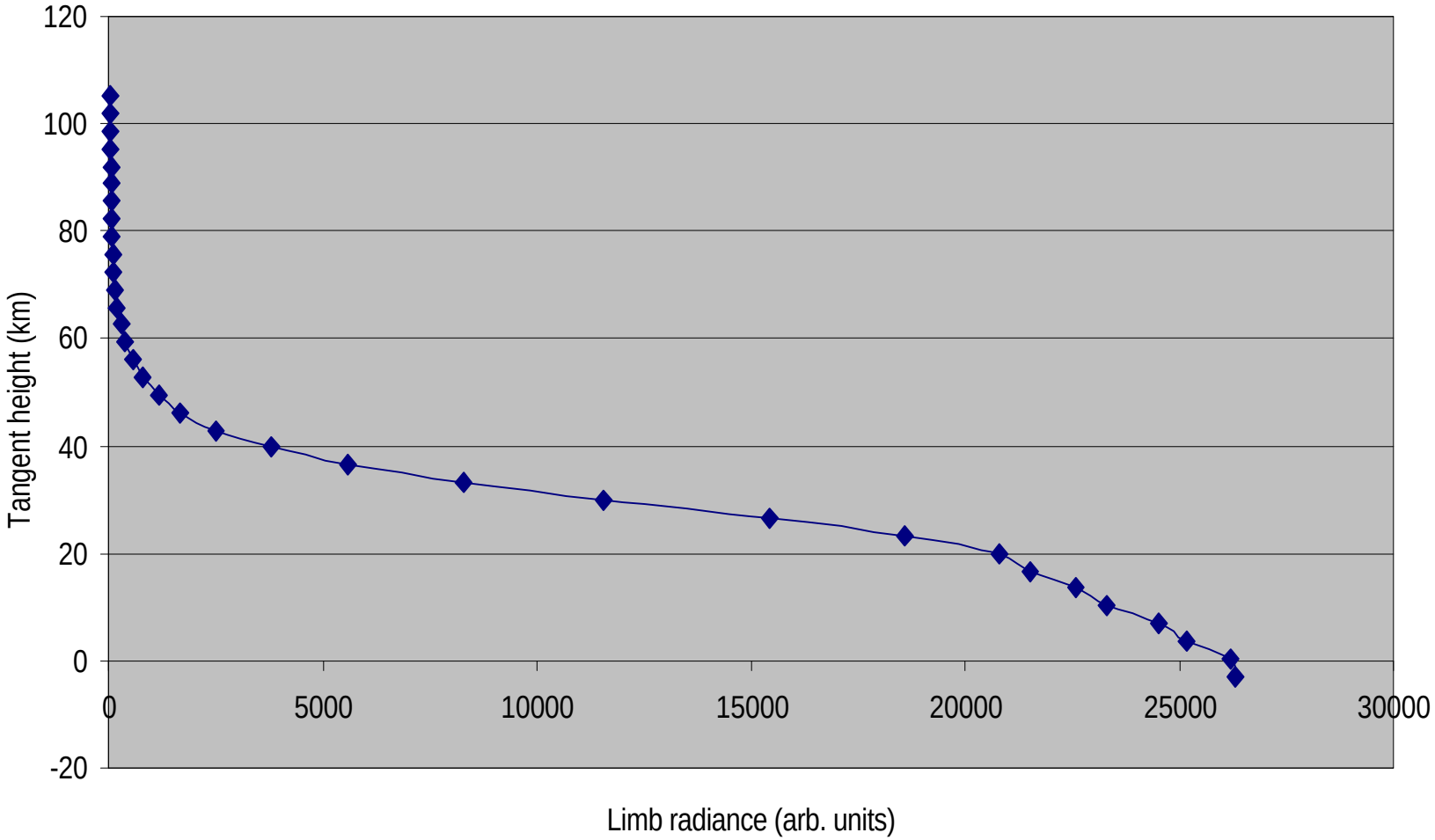
- 1 km error in tangent height (TH) can lead to O_3 retrieval errors of 30% at z=20 km (Flittner *et al.*, 2000)

OSIRIS



MODTRAN4





345 nm limb radiance profile from **SCIAMACHY** over the Himalayas, July 1st, 2002 (no 'knee'!)

Method

1) locate the ‘knee’, defined as the maximum in the observed limb radiance profile, at a single scattering λ (i.e.305 nm) not affected by internal scattering.

2) get knee height from look up table generated using RT model, with only 3 dimensions:

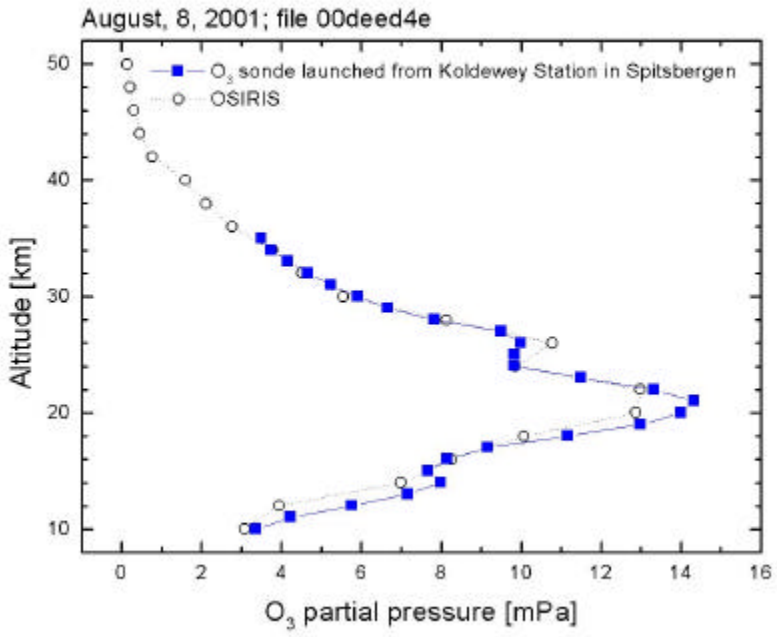
a) ozone profile,
b) pressure profile,
c) SZA

3) correct altitude registration using difference between 1) and 2)

-insensitivity of knee to spatially variable geophysical parameters implies that instrument measuring limb radiance profile need not vertically image for technique to be applicable (i.e. applies to limb scanners)

Precision: 0.5 × vertical sampling (km) at TH=45 km or 0.7 km, whichever is greater

-305 nm knee occurs at a TH where radiance is very predictable because:
1) overlying ozone column is fairly invariable
2) molecular scattering dominates



Reference:

Flittner, D. E., P. K. Bhartia, and B. M. Herman, O_3 profiles retrieved from limb scatter measurements: Theory, *Geophys. Res. Lett.*, **27**, 2601-2604, 2000.

Summary of Sensitivity Study

Variable(s)	Knee sensitivity (km)
O_3 profile: tropical vs. subarctic winter (subarc-w)	+1
Pressure: tropical vs. subarc-w	+3
O_3 & pressure (tropical vs. subarc-w)	+3
SZA: 90 vs 57º	+2
O_3, pressure & SZA (tropical vs. subarc-w, 87.7 vs 57º)	+4
Optically thick stratospheric cloud[#]	0
Ground albedo (A=0 or 1)	0
Temperature (subarc-s vs. tropical vs. subarc-w)	0
Azimuthal angle ($d\phi$= 60 to 120º)	0

[#]An optically thick (τ=8 at 305 nm) cloud was inserted into the stratosphere (cloud top= 30 km)

‘Spectral knee’ method works well because:

- Ozone absorption prevents upwelling radiation from troposphere, lower stratosphere (insensitive to clouds, aerosols, surface albedo)
- ozone distribution is largely governed by photochemistry above 40 km
- 280-305 nm knees peak at heights where molecular scattering dominates (no clouds in FOV)
- O_3 absorption is weakly temperature dependent in this spectral window
- spectral sampling is used to overcome vertical undersampling

Additional Notes

- The major remaining question is how well the pointing offsets are known when one pressure level is determined.

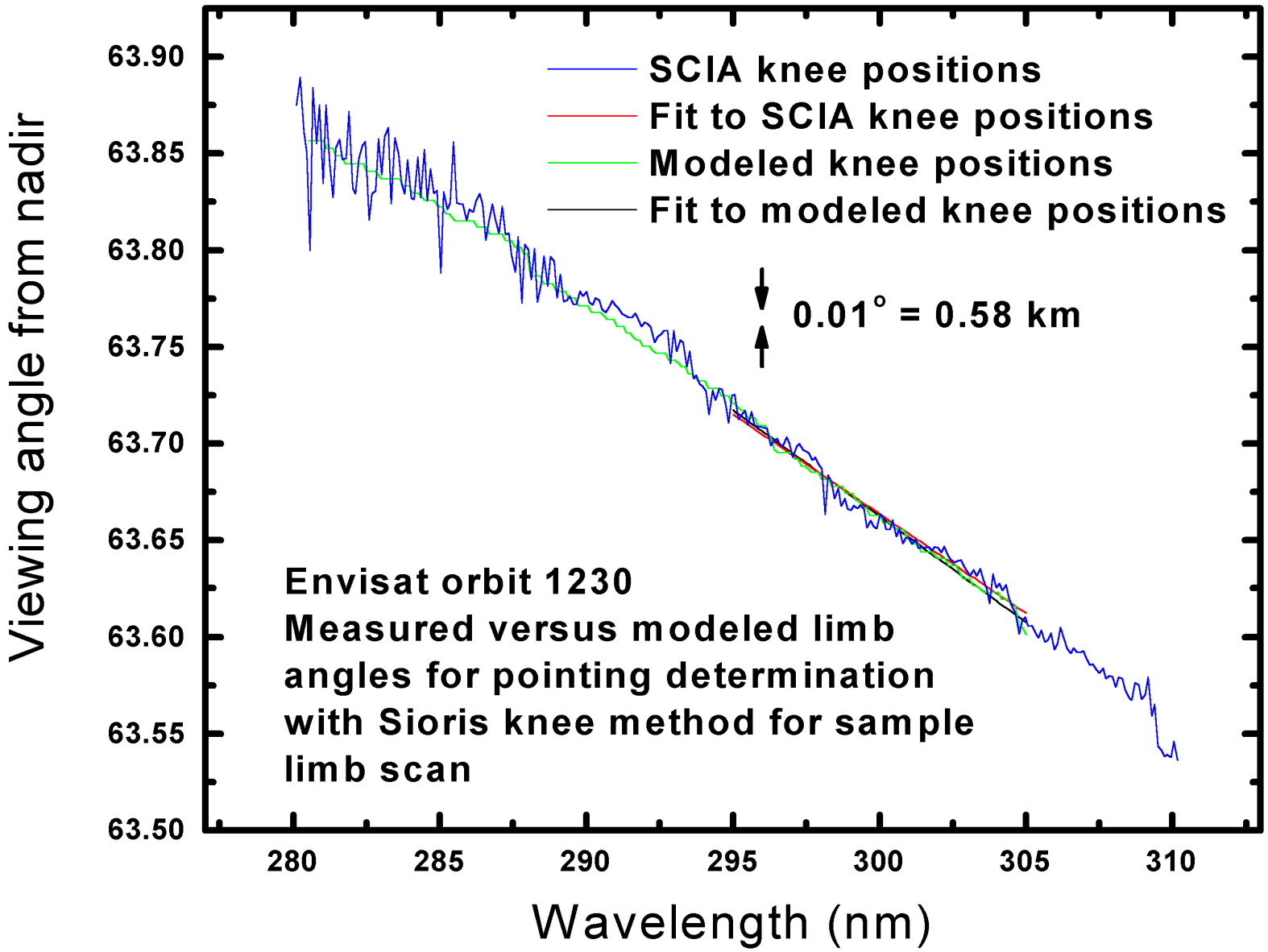
- For pressure level determination most error terms disappear (determination is to 3% in ln (P) or 0.2 km); the question is how well the upper-level stratospheric photochemistry is known.

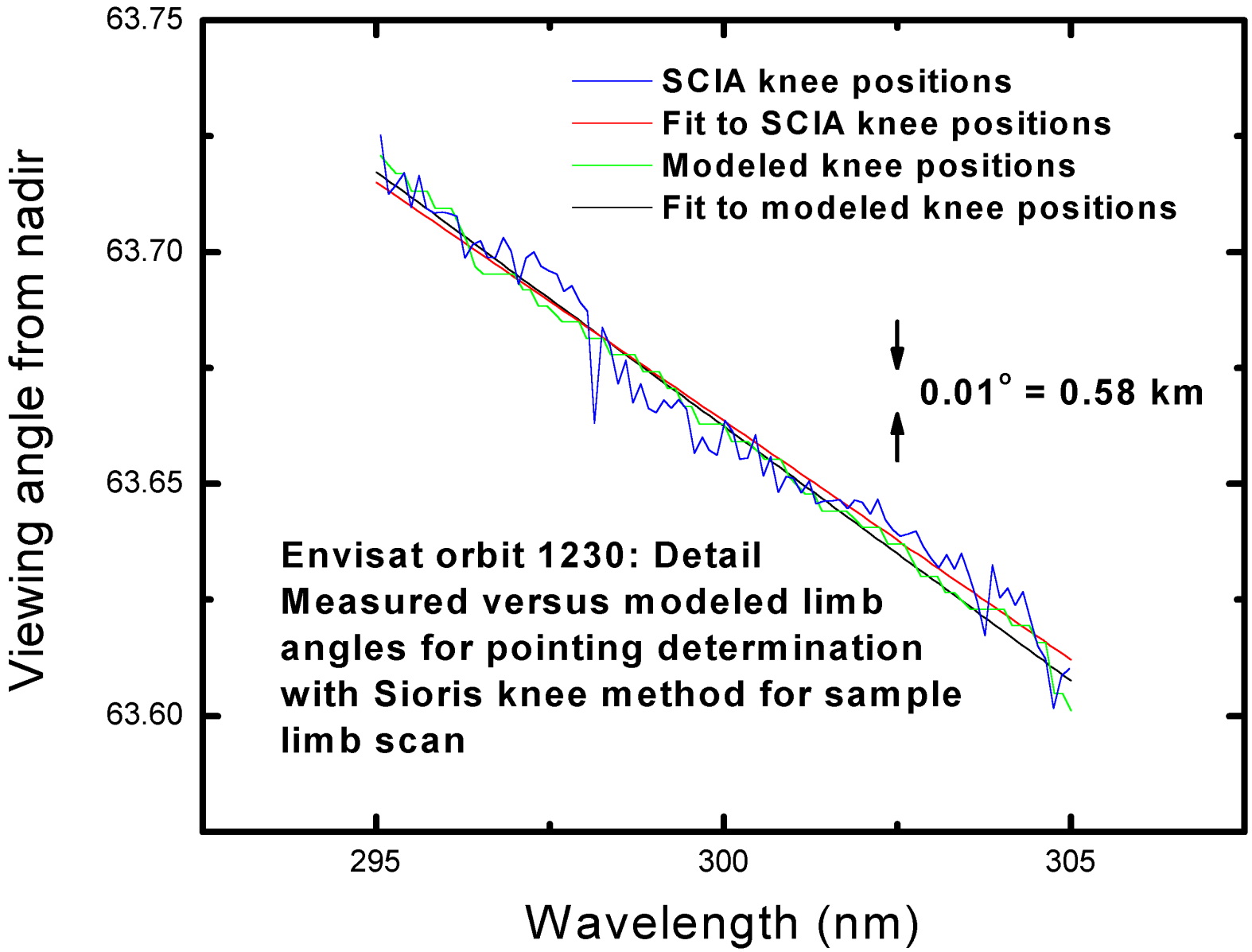
Knees at Multiple Wavelengths

- During the last SADDU meeting, SAO introduced the concept of measuring knees at multiple wavelengths, to improve the overall pointing determination when offset is the major contributor to pointing uncertainty.

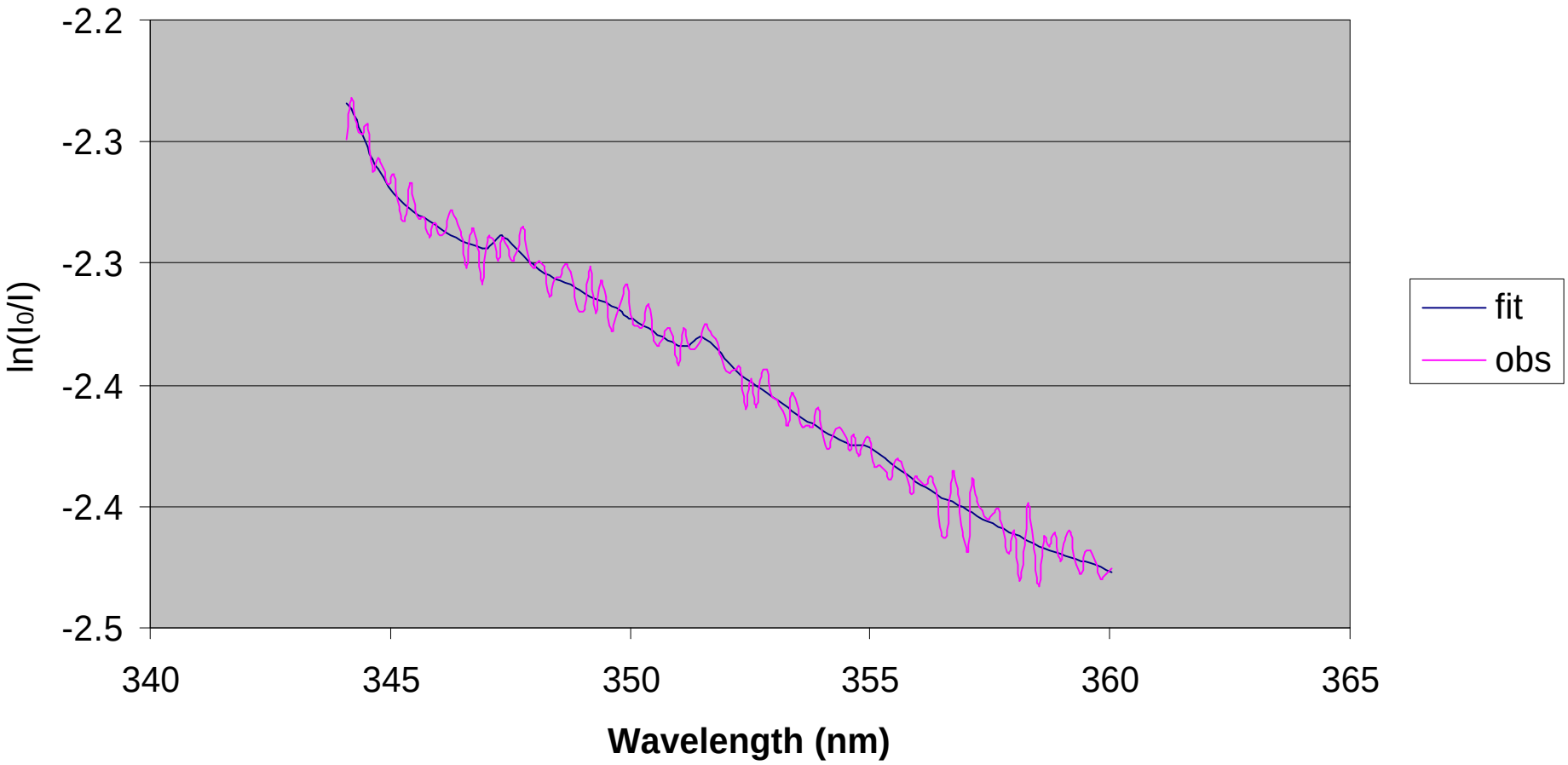
- Determination of knees at a number of wavelengths at 305 nm and shorter (limited by instrument scattering) improves sampling similar to that given by higher limb sampling frequency, since different wavelengths exhibit knees at different tangent heights.

- IFE has adopted this concept as the basis for their “TRUE algorithm.”

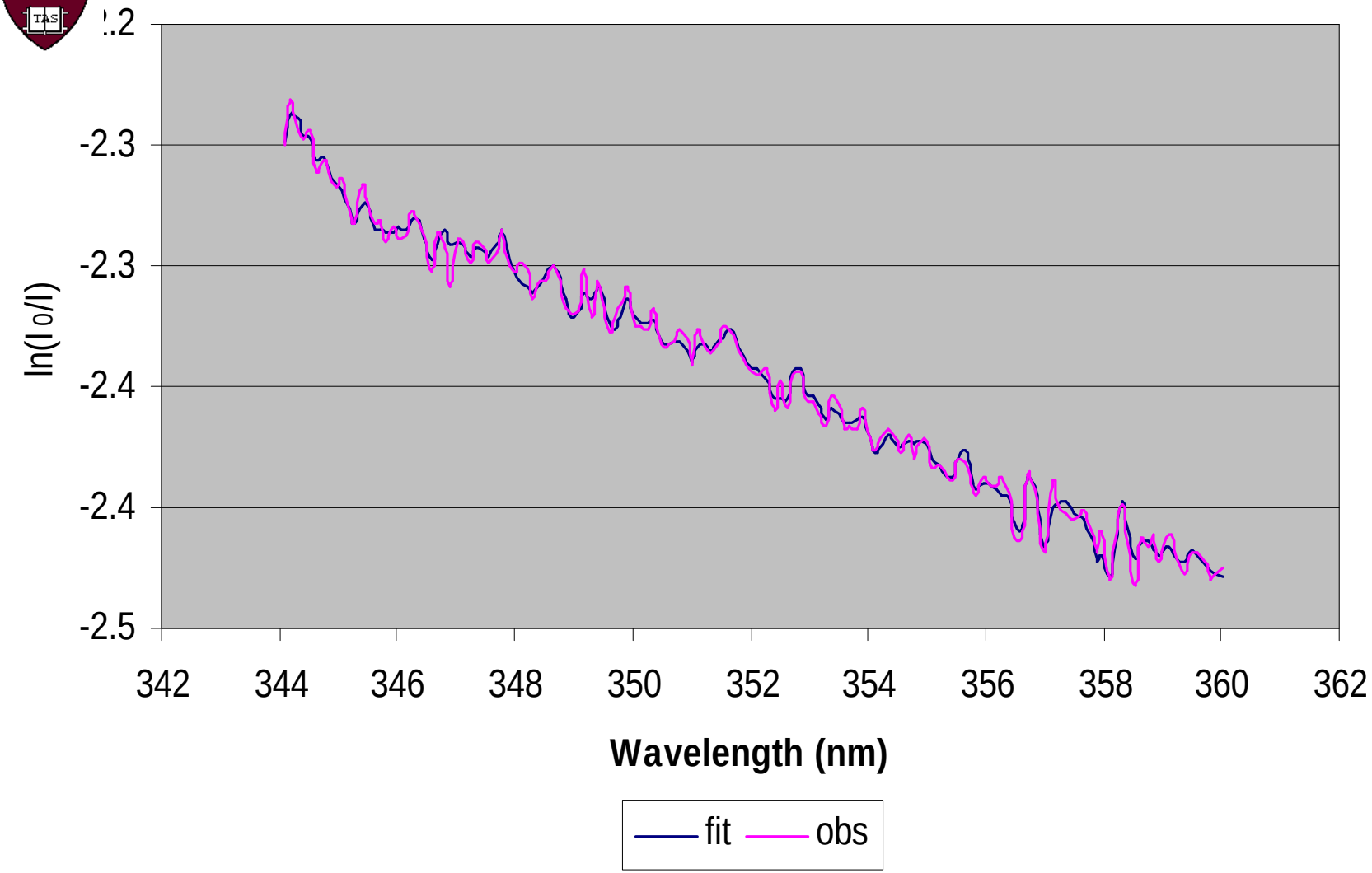

SCIA knee positions
Fit to SCIA knee positions
Modeled knee positions
Fit to modeled knee positions
0.01° = 0.58 km
Envisat orbit 1230
Measured versus modeled limb angles for pointing determination with Sioris knee method for sample limb scan
Viewing angle from nadir
63.90
63.85
63.80
63.75
63.70
63.65
63.60
63.55
63.50
280
285
290
295
300
305
310
Wavelength (nm)


63.75
63.70
63.65
63.60
Viewing angle from nadir
295
300
305
Wavelength (nm)
SCIA knee positions
Fit to SCIA knee positions
Modeled knee positions
Fit to modeled knee positions
0.01° = 0.58 km
Envisat orbit 1230: Detail
Measured versus modeled limb
angles for pointing determination
with Sioris knee method for sample
limb scan

Discovery of a new pseudo-absorber related to Fraunhofer structure



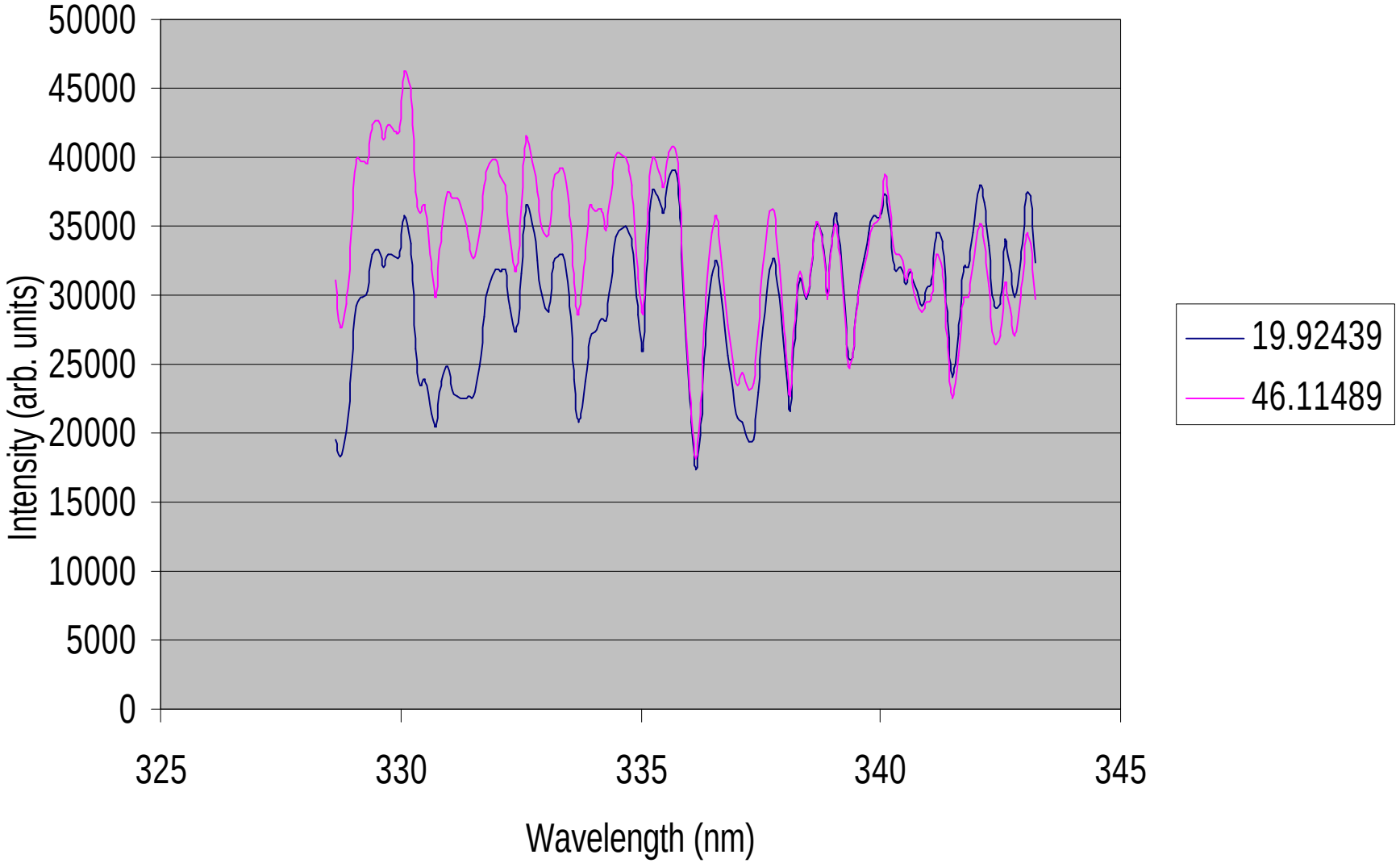
Fit of observed normalized spectral radiance with O_3, NO_2, (including temperature dependence), BrO, and a cubic polynomial



with ‘Tilt’ now included.

It is the second most important basis function in the linear regression model besides the 0th order term!

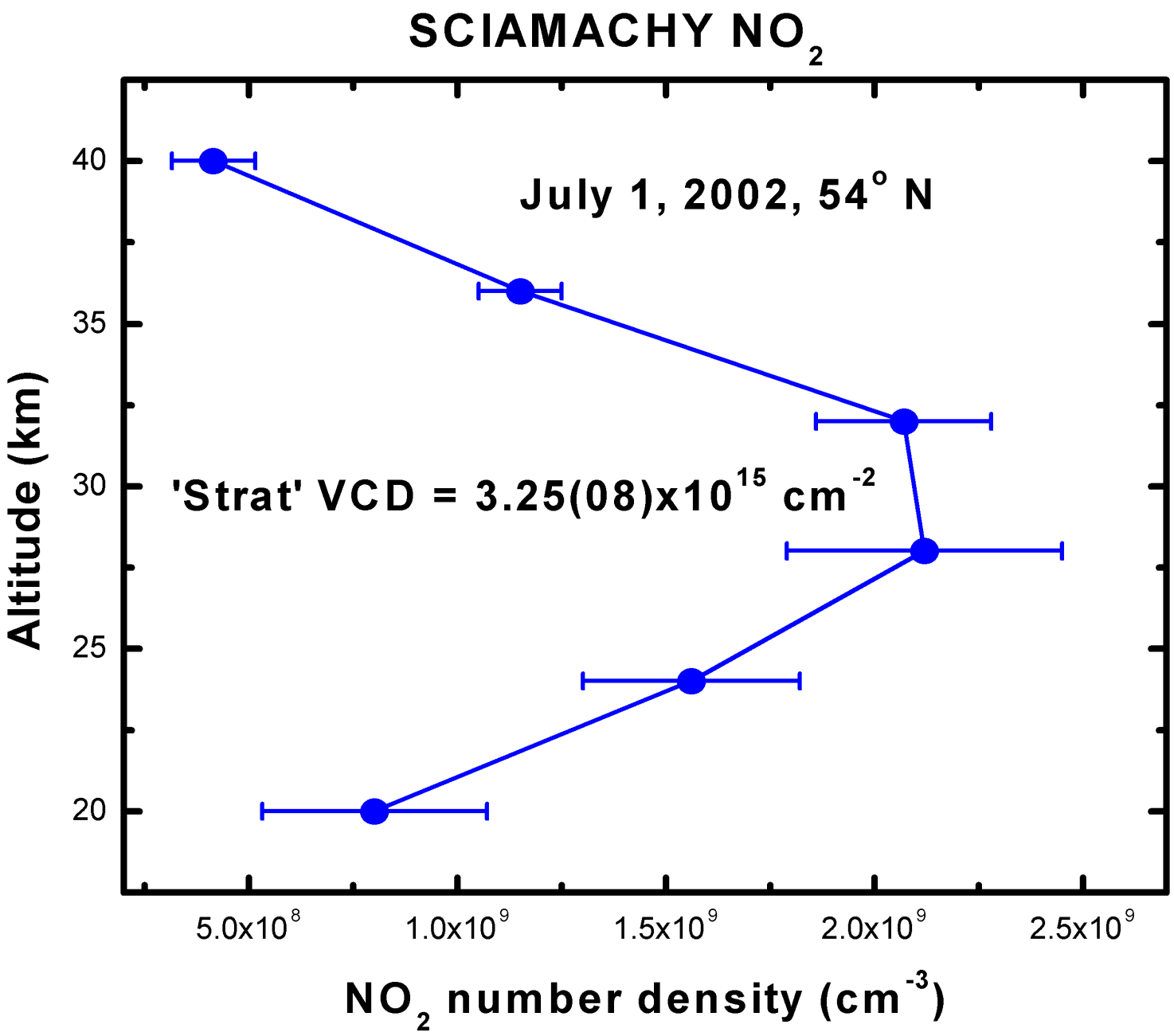
Pseudo-absorber named ‘tilt’

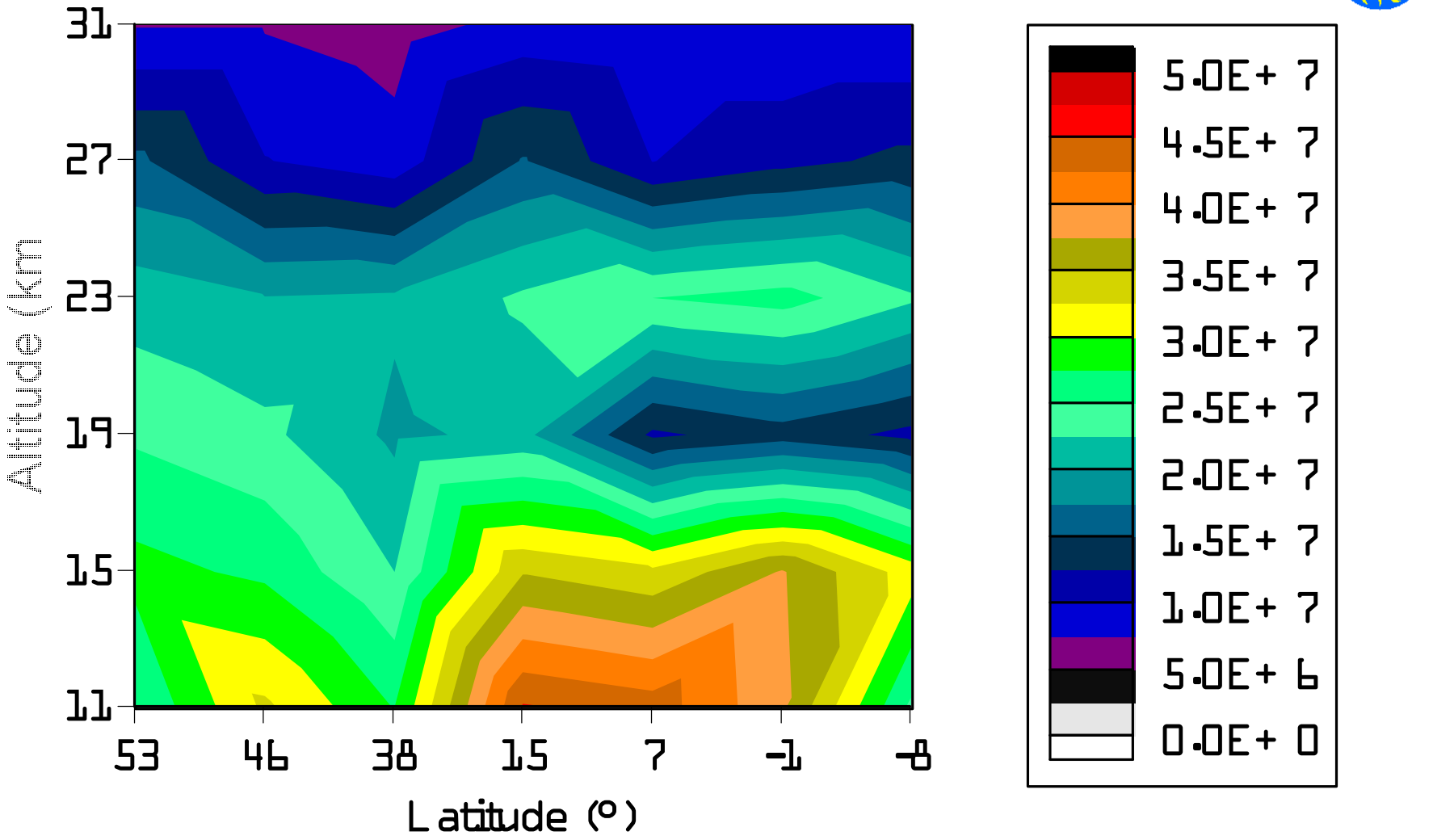


$I_{TH=46}$ has been scaled to $I_{TH=19.9\ km}$

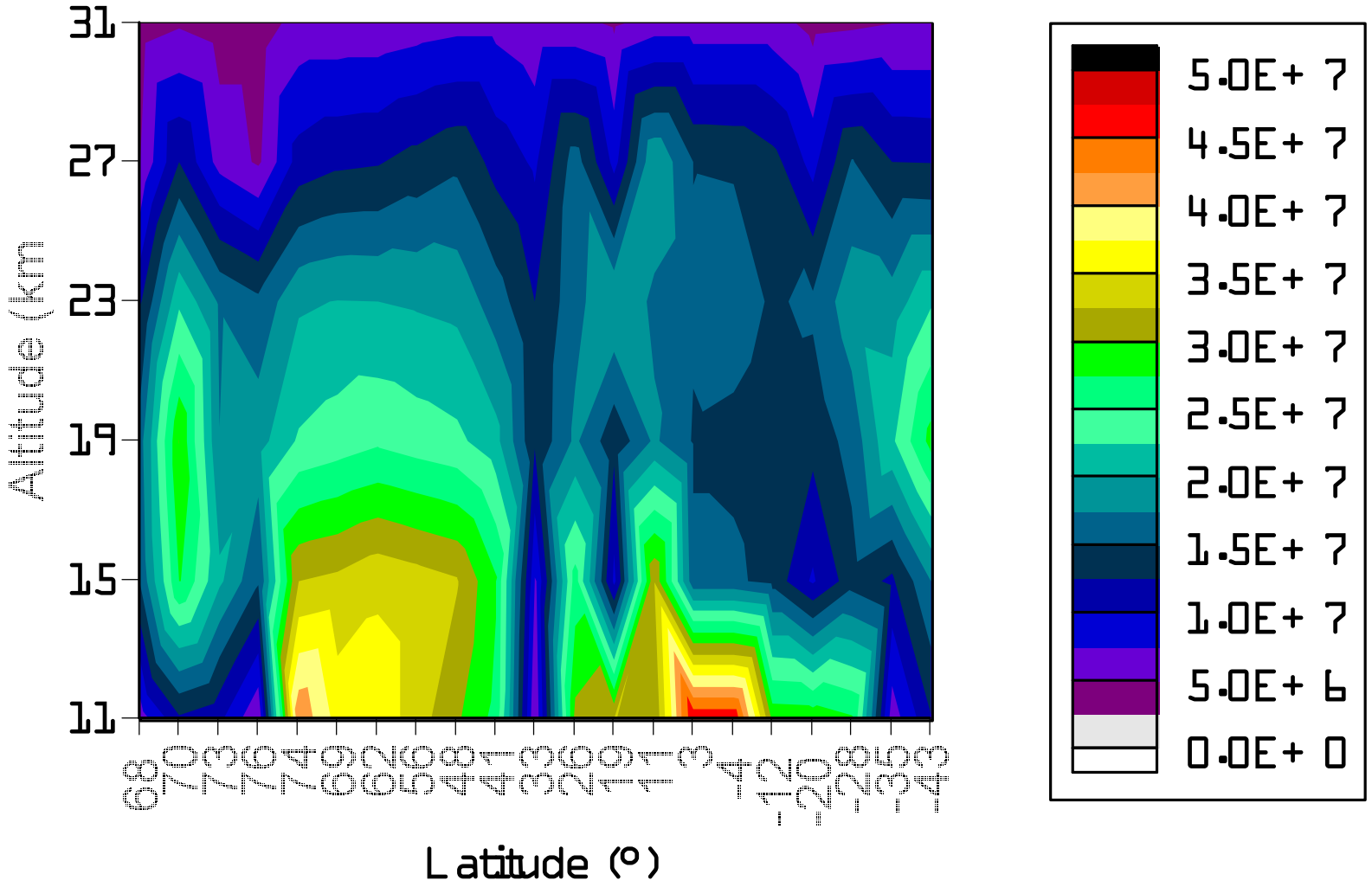
HOW TO ACCOUNT FOR FINE STRUCTURE DUE TO TILT IN LIMB OBSERVATIONS:

- simulate I and I_0 at high spectral resolution in a non-absorbing atmosphere (no O_3, etc.)
- convolve and bin each spectrum according to SCIA characteristics
- normalize (take I/I_0 ratio)
- de-trend with a polynomial
- fit as a pseudo-absorber (assume that the tilt spectrum simply scales vs. TH) [Sioris *et al.*, submitted to JGR]


SCIAMACHY NO2
July 1, 2002, 54° N
'Strat' VCD = 3.25(08)x10^15 cm^-2
Altitude (km)
40
35
30
25
20
5.0x10^8
1.0x10^9
1.5x10^9
2.0x10^9
2.5x10^9
NO2 number density (cm^-3)



BrO meridional cross-section on July 1st, 2002 (molec/cm^3). Tropical upper tropospheric enhancement is off the west coast of India.



BrO meridional cross section for July 24th, 2002.
Tropical enhancement is off the east coast of Africa.