



the  
**abdus salam**  
international centre for theoretical physics

SMR: 1133/29

*WINTER COLLEGE ON  
SPECTROSCOPY AND APPLICATIONS*

( 8 - 26 February 1999)

---

*"Remote Sensing of the Atmosphere"*

presented by:

**Ludger WÖSTE**

Freie Universität Berlin  
Institut für Experimentalphysik  
Arnimallee 14  
D-14195  
Germany

---

These are preliminary lecture notes, intended only for distribution to participants.

strada costiera, 11 - 34014 trieste italy - tel. +39 0402240111 fax +39 040224163 - sci\_info@ictp.trieste.it - www.ictp.trieste.it



# Remote Sensing of the Atmosphere

## 1st day

### Lidar-measurements of Atmospheric Pollution

- Why Lidar
- The DIAL principle
- Pollution sources
- Propagation of Pollution
- Topographic Aspects
- Winter Smog and Summer Smog

## 2nd day

### Chemistry and Physics of Air Pollution

- The structure of the Atmosphere
- The greenhouse effect
- The role of Ozone in the Atmosphere
- The tropospheric Ozone increase
- The stratospheric Ozone depletion
- The role of Polar Stratospheric Clouds

## 3rd day

### Lidar-and Laboratory investigation of aerosols

- Spectral signatures of aerosols
- The multiwavelength Lidar
- Arctic PSC - measurements
- Laboratory experiments in a Paul trap
- Nucleation, Growth and Decay of Aerosols

# LIDAR Measurements of Atmospheric Air Pollution

## Collaborators

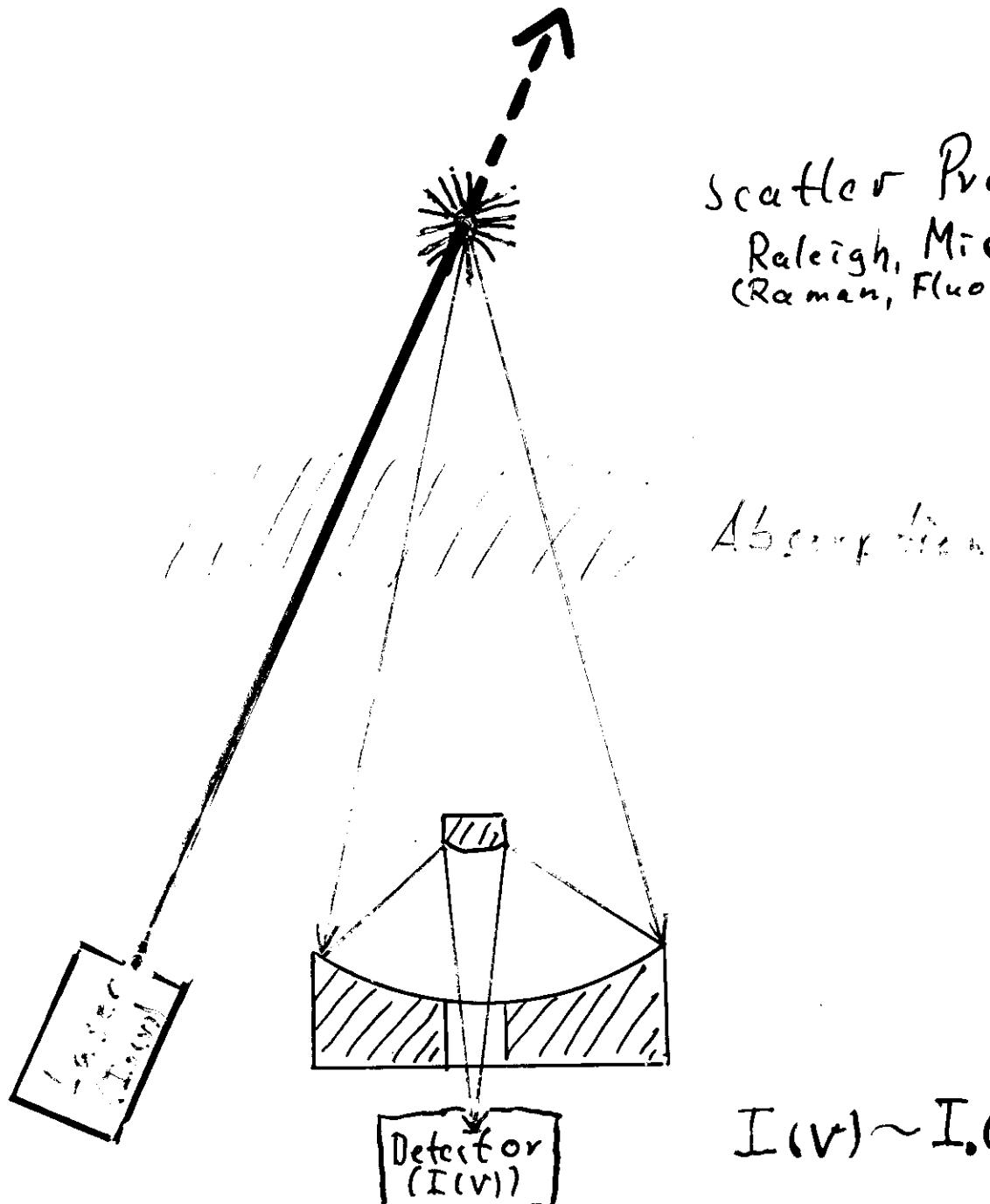
J. P. Wolf  
H. J. Kölsch  
P. Rairoux  
B. Stein  
C. Wedekind  
F. Immel  
St. Frey  
B. Mielke  
D. Weidauer  
D. Waite  
M. Müller  
W. Zimmer  
M. Rodriguez  
H. Wille

## Collaborations

M. Ulbricht (Erlangen)  
D. Weidauer ( " )  
J. P. Wolf (Lyon)  
P. Rairoux (Cottbus)  
K. Fritzsche (Leipzig)  
E. Kyrö (Finland)  
L. Stefanutti (Florenz)  
R. Sauvabrey (Jena)  
H. Schillinger ( " )  
F. Ronneberger ( " )  
St. Niedermeyer ( " )

# L I D A R

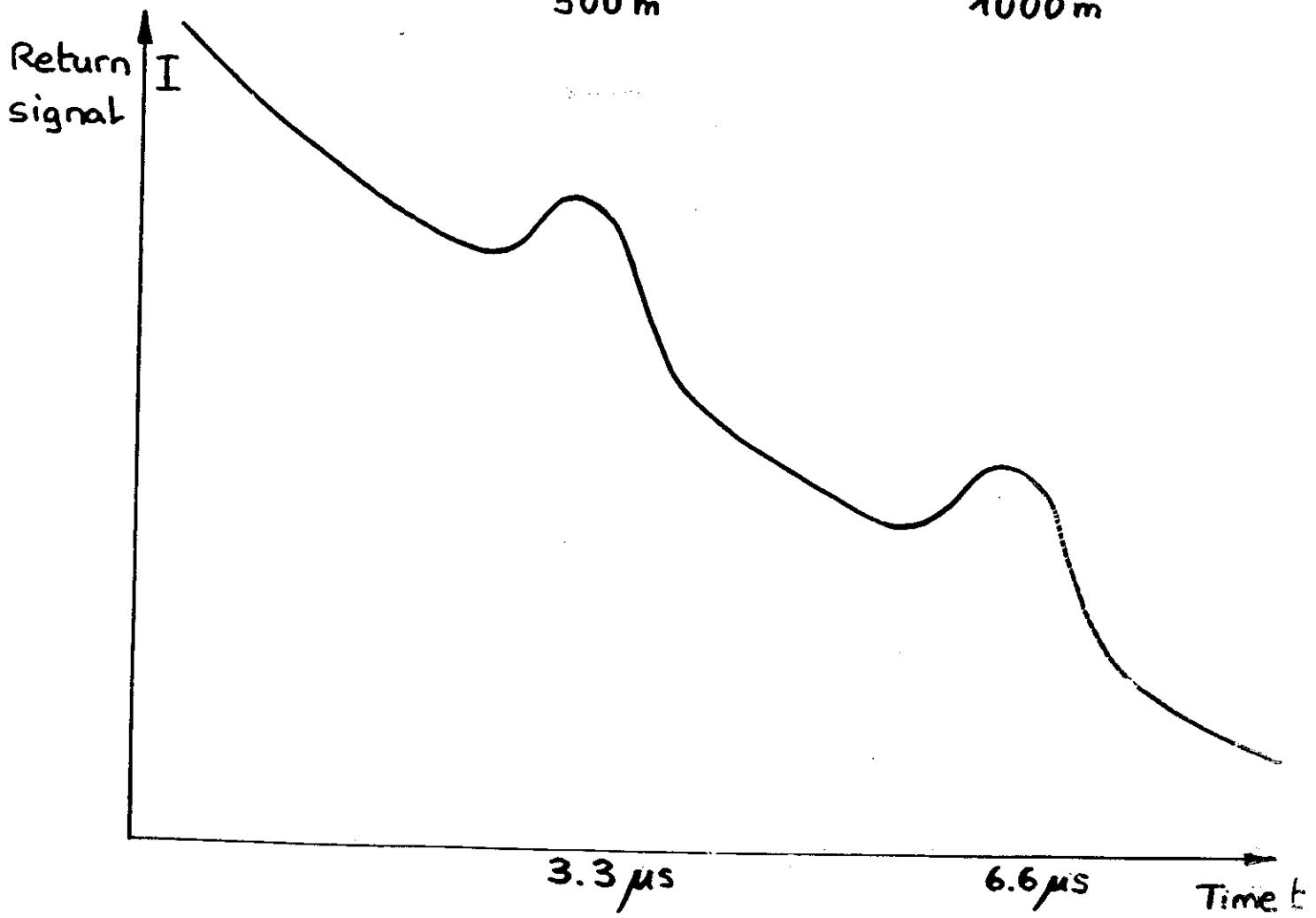
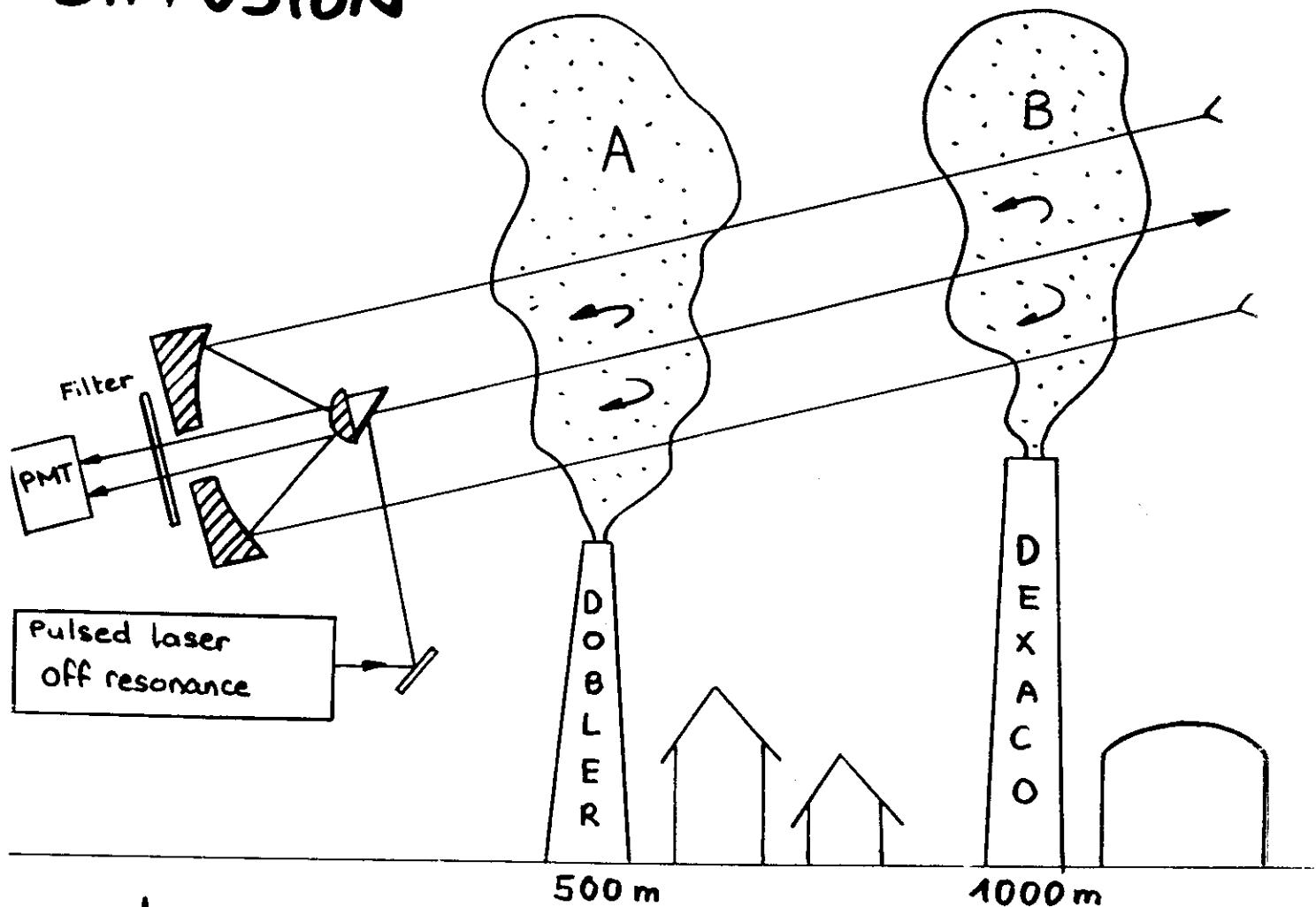
Light - Detection and Ranging



$$I(v) \sim I_0(v) \frac{A}{R^2}$$

# DIFFUSION

-6-



## LIDAR EQUATION

The number of photons  $M(R, \lambda)$  backscattered from a layer of depth  $\Delta R$  at a distance  $R$  can be written as

$$M(R, \lambda) = M_0(\lambda) \cdot \frac{A}{R^2} \cdot \beta(R, \lambda) \cdot \Delta R \cdot \xi(R, \lambda) \cdot e^{-2 \int_{\text{bottom}}^R K(\lambda, R') dR'}$$

where  $M_0(\lambda)$  is the number of photons emitted per laser pulse at wavelength  $\lambda$ ,

-  $A$  the area of the receiving mirror,

-  $\beta(R, \lambda) = n_s(R) \left[ \frac{d\sigma}{d\Omega}(\lambda) \right]_{\pi}$  describes the backscattering by a medium of density  $n_s$

and differential cross section for backscattering

$$\left[ \frac{d\sigma}{d\Omega}(\lambda) \right]_{\pi}$$

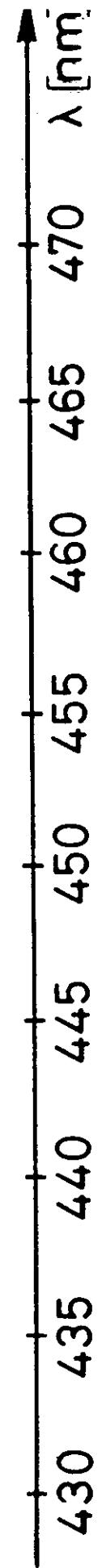
-  $\xi(R, \lambda)$  represents the detection efficiency

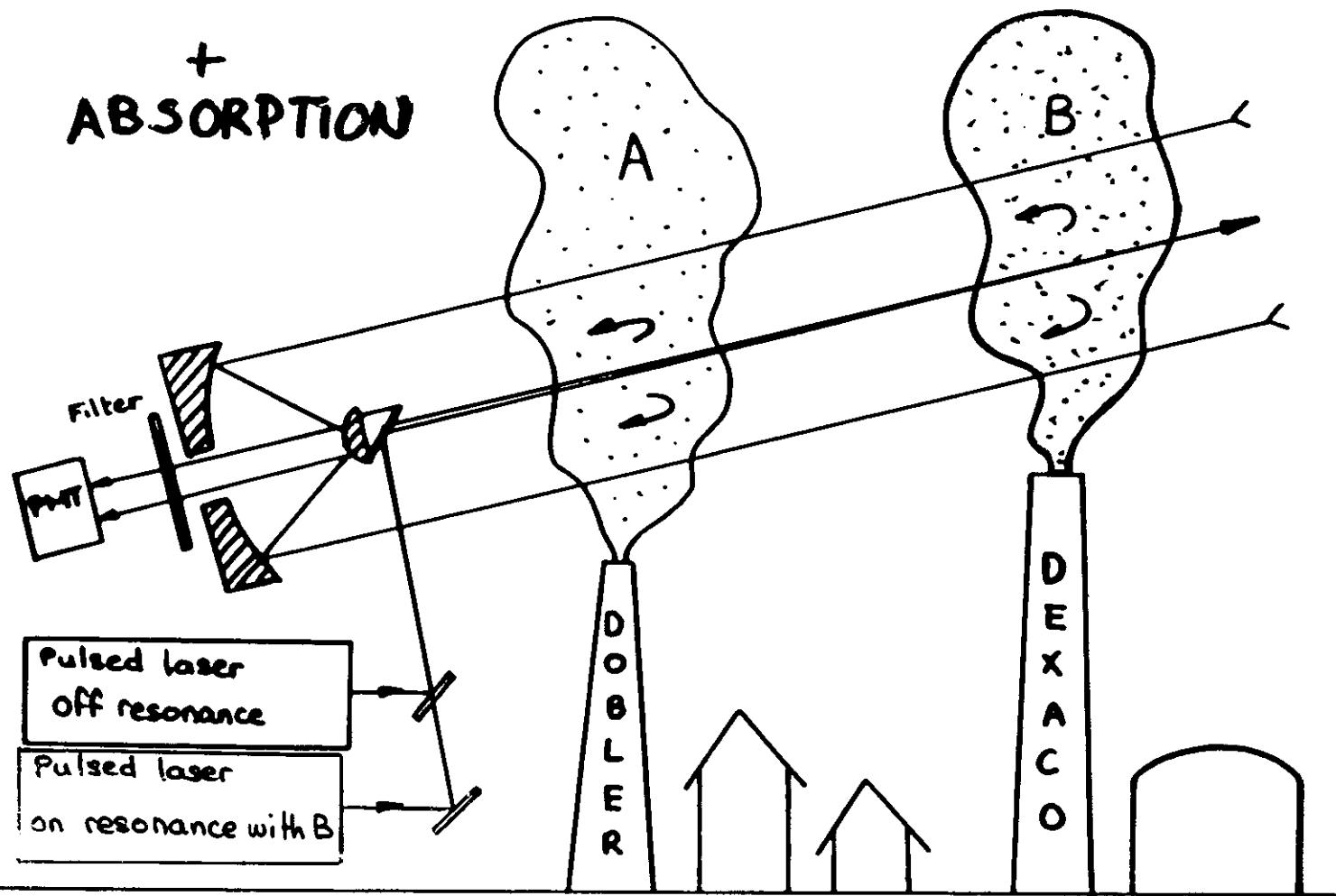
-  $K(\lambda, R) = \sum_{i=1}^n \{ K_{\text{Rayleigh}}^i(\lambda, R) + K_{\text{Absorption}}^i(\lambda, R) \} + K_{\text{Hie}}(\lambda)$   
is the total attenuation coefficient for the  $n$  atmospheric constituents.

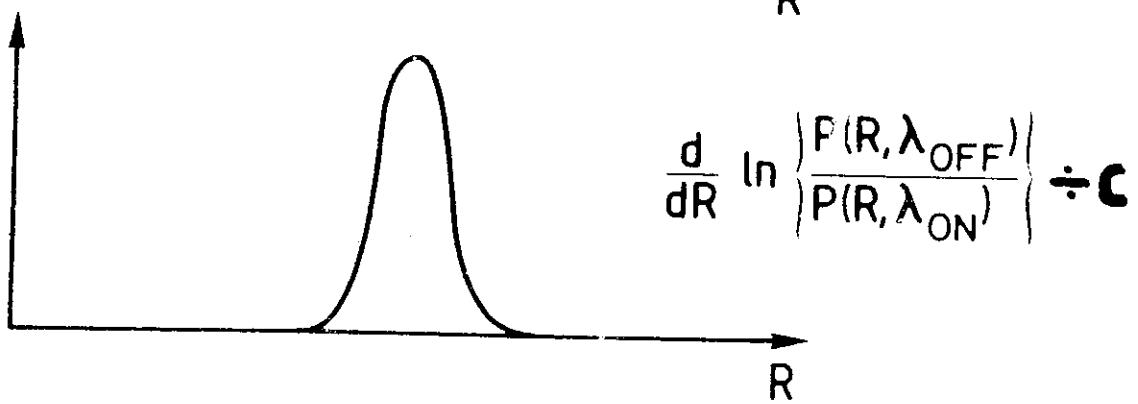
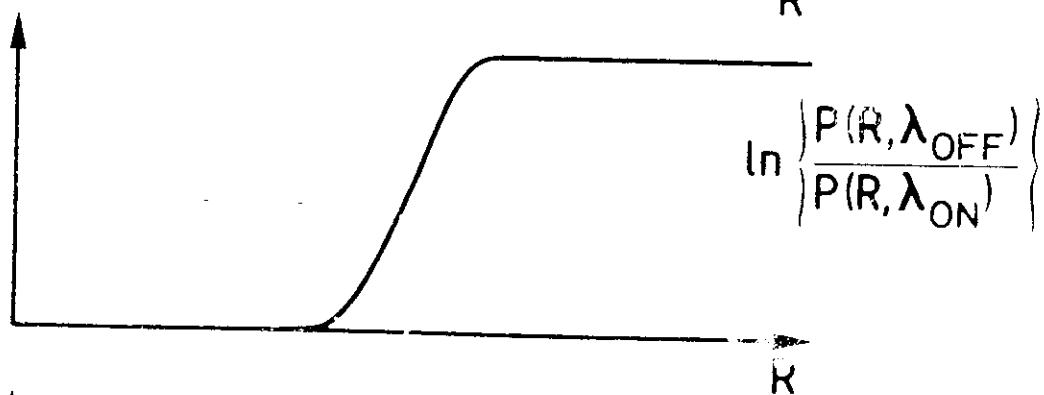
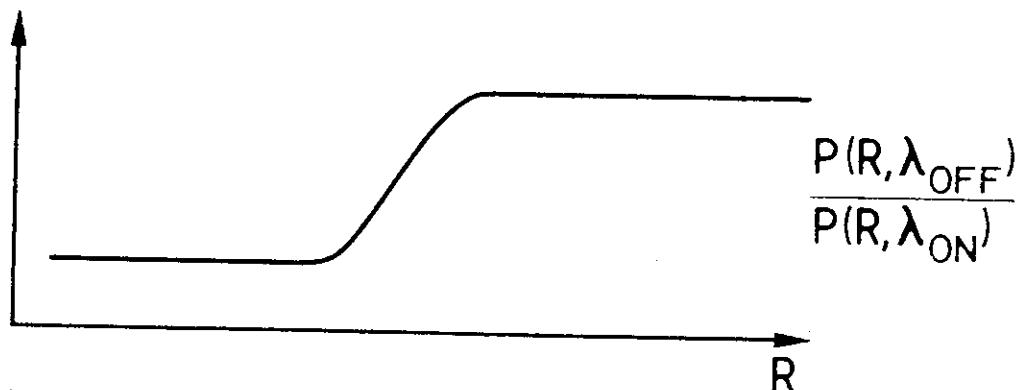
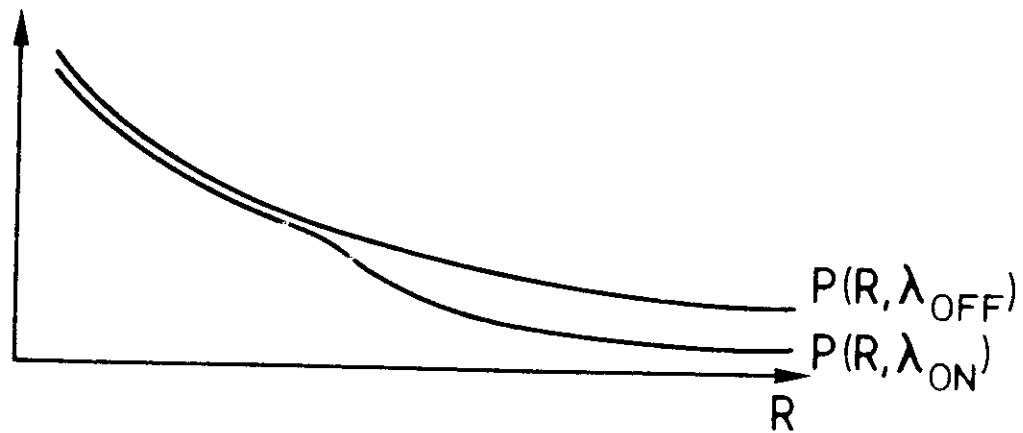
-NO<sub>2</sub> spectrum -  
200ppm in 760 torr N<sub>2</sub>

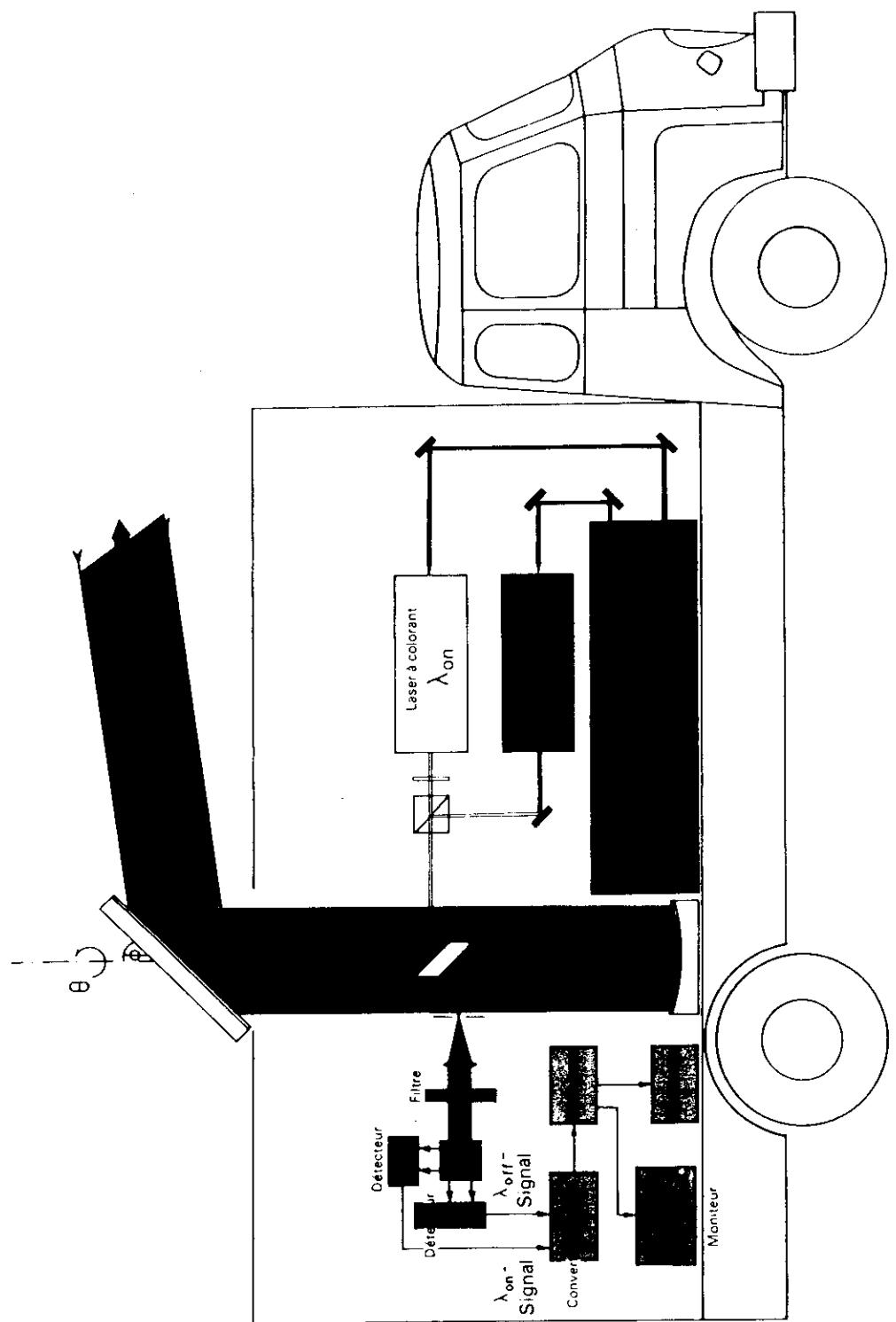
$$\lambda_{\text{ON}} = 448.1 \text{ nm}$$

$$\lambda_{\text{OFF}} = 446.5 \text{ nm}$$



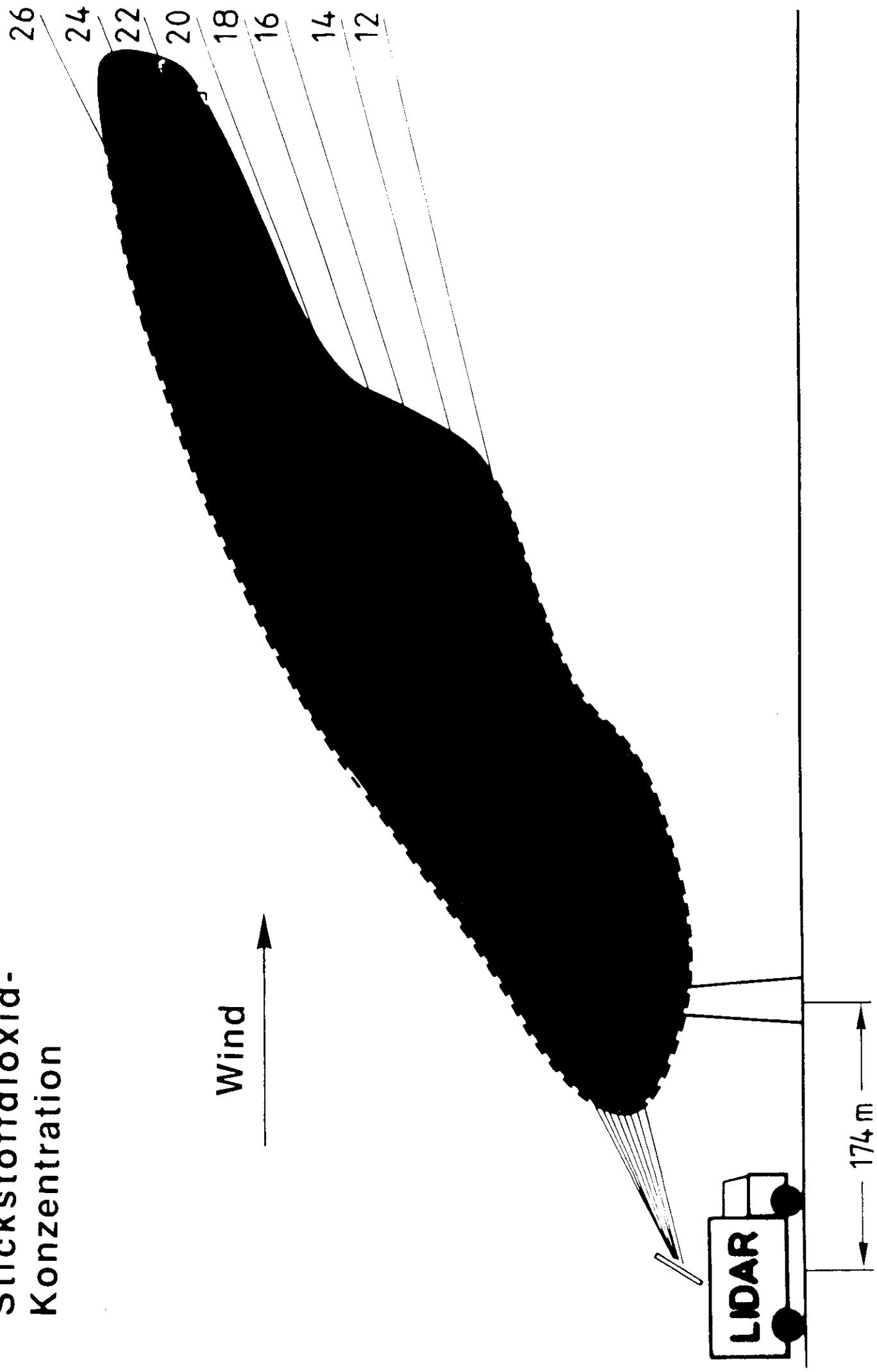




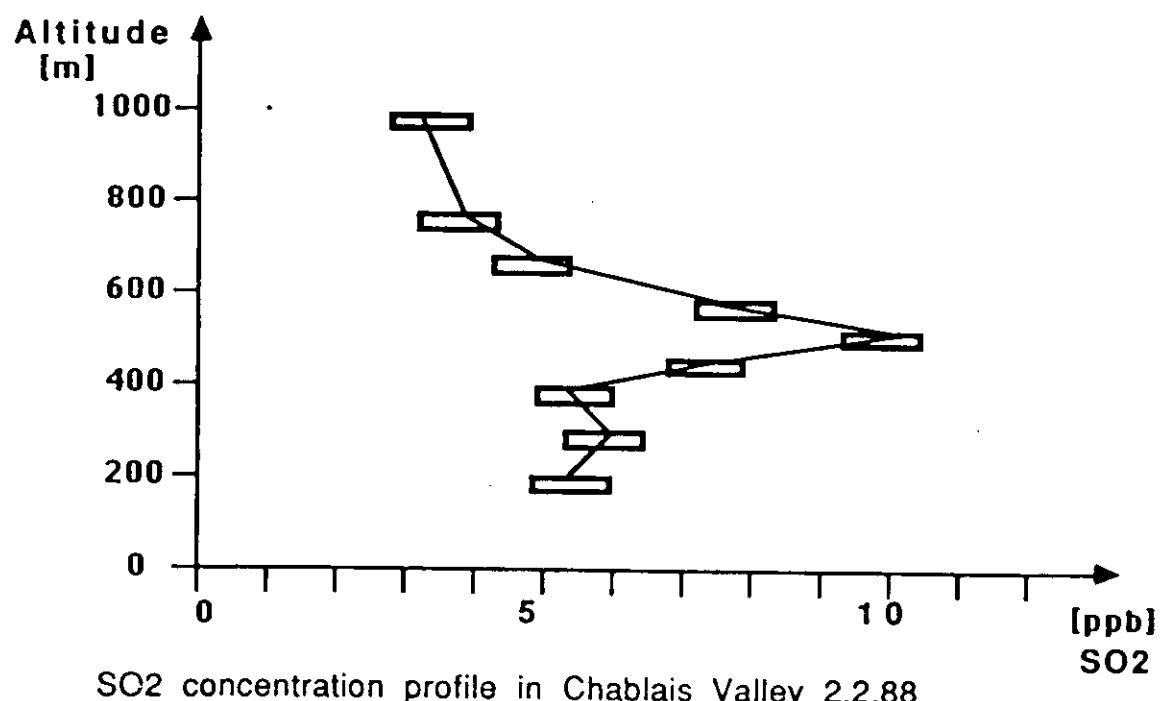
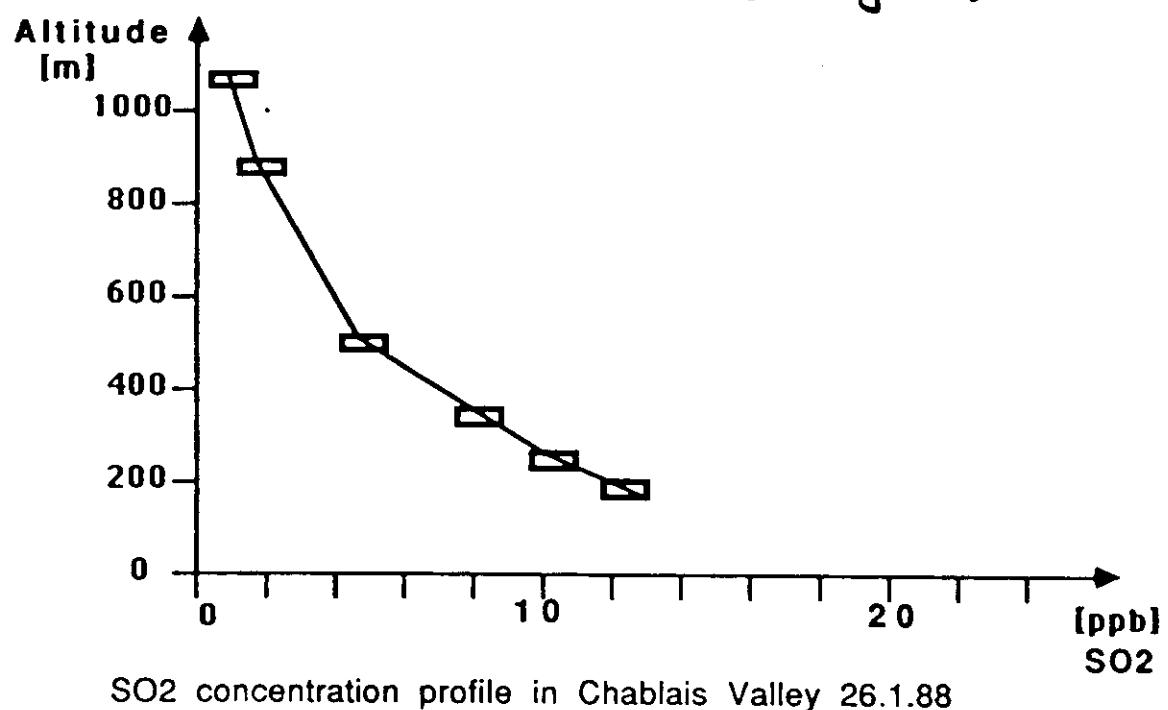


Experimentalaufbau des Systems

# Stickstoffdioxid-Konzentration

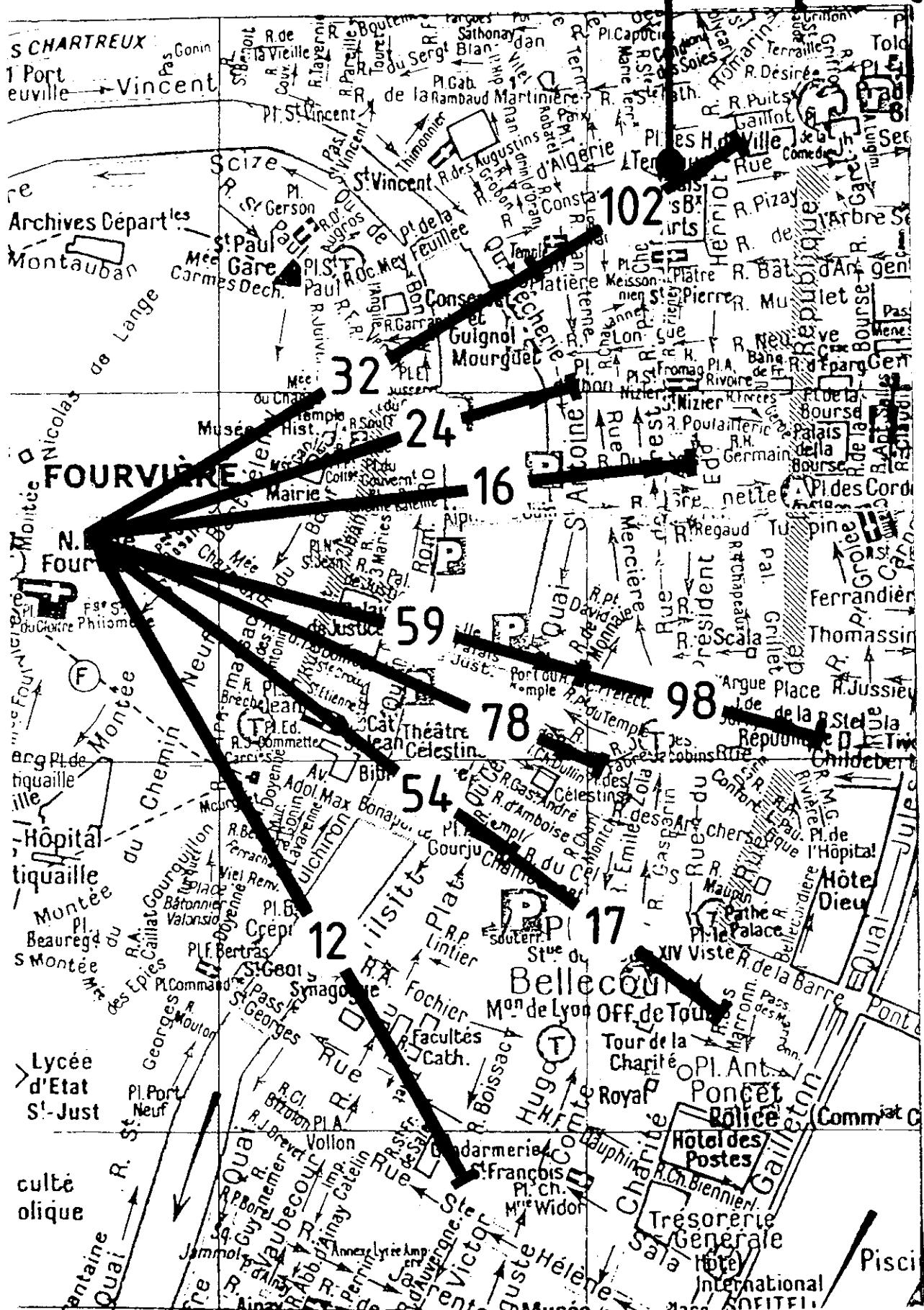


Detection limit : 500 ppt  
Measurement range : upto 20kr  
(integral)



NO-Konz.

ppb

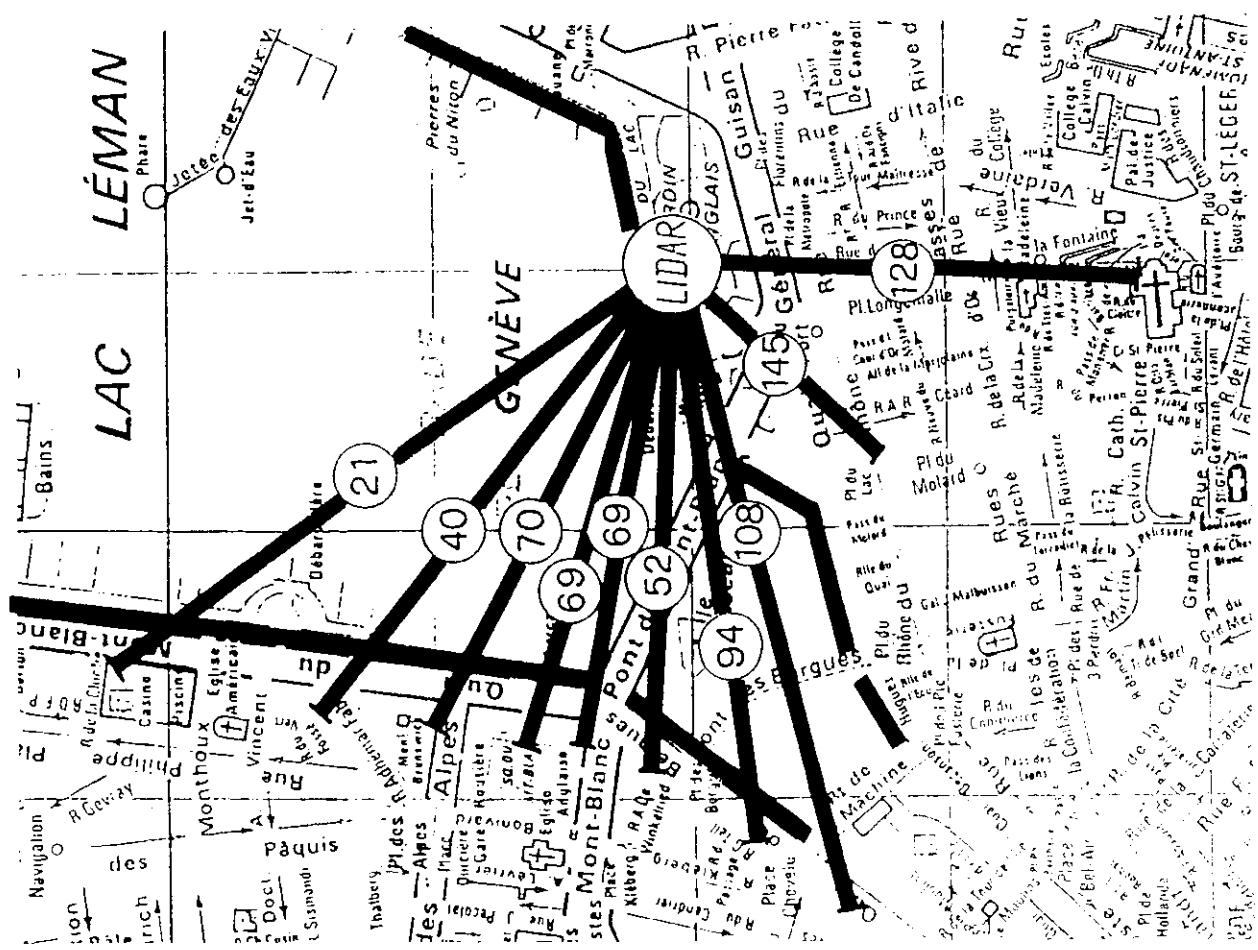
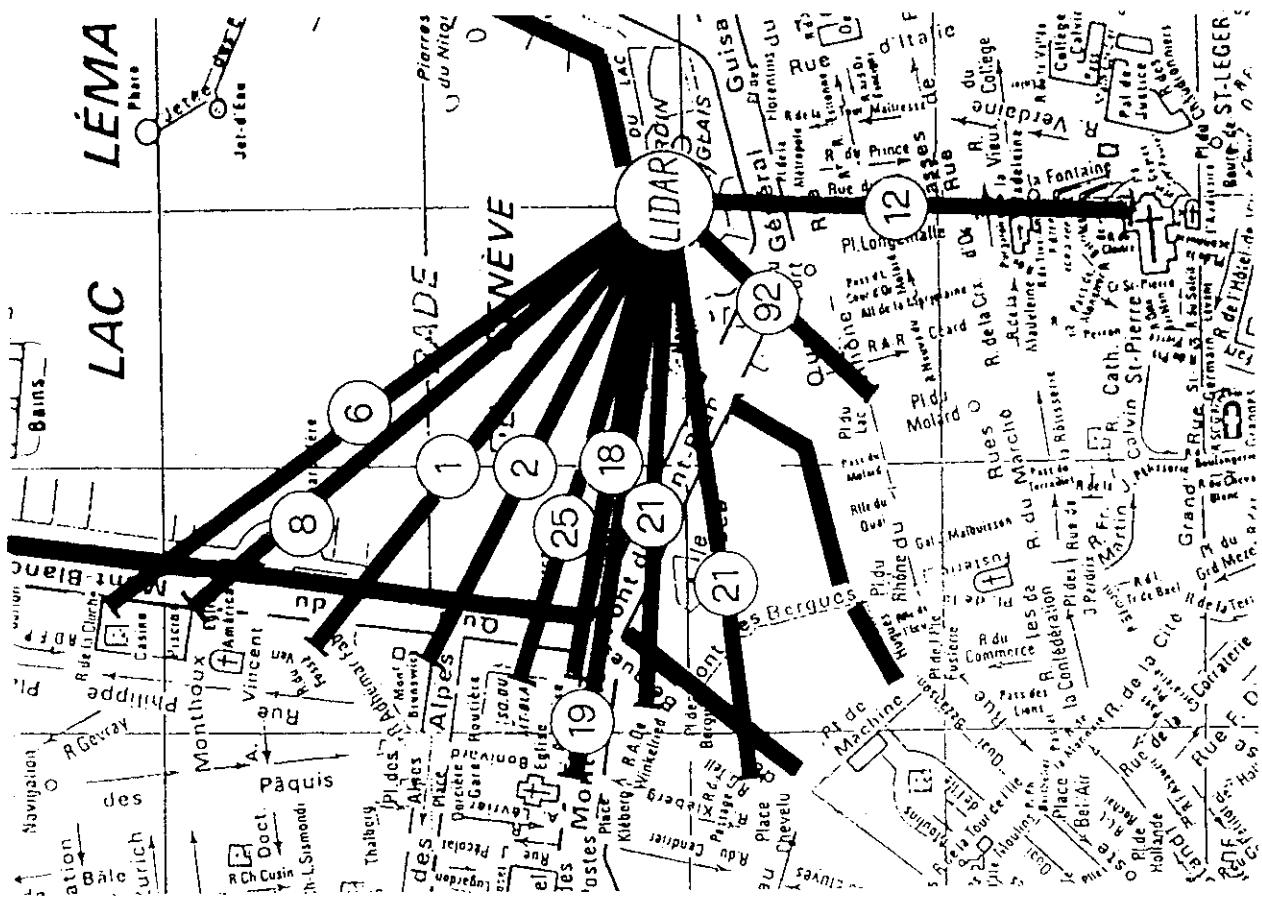


Lyon

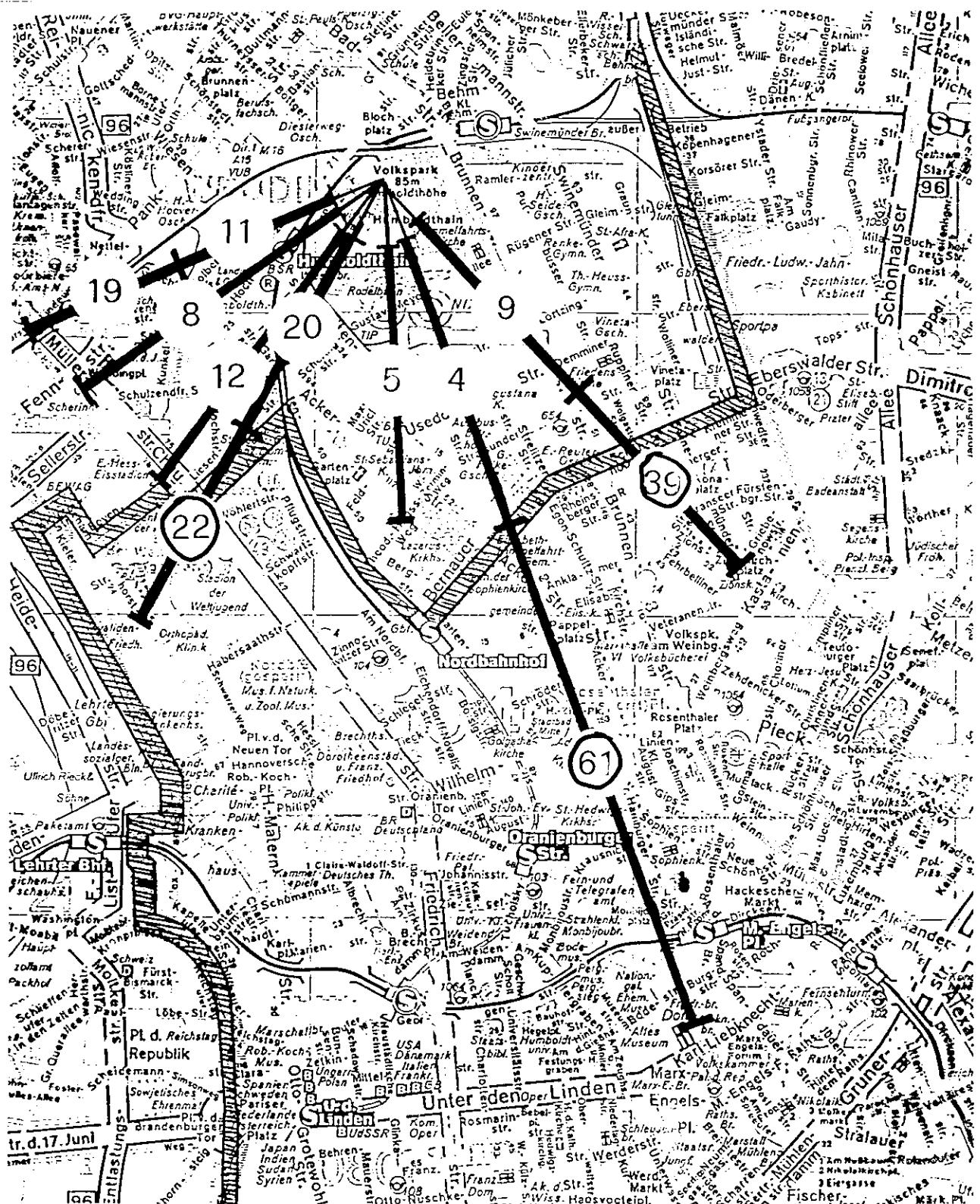
500 m

Gen 4

(conc.) M



## Horizontal SO<sub>2</sub> distribution over Berlin on December 14, 1988



[ppb]

1000 m

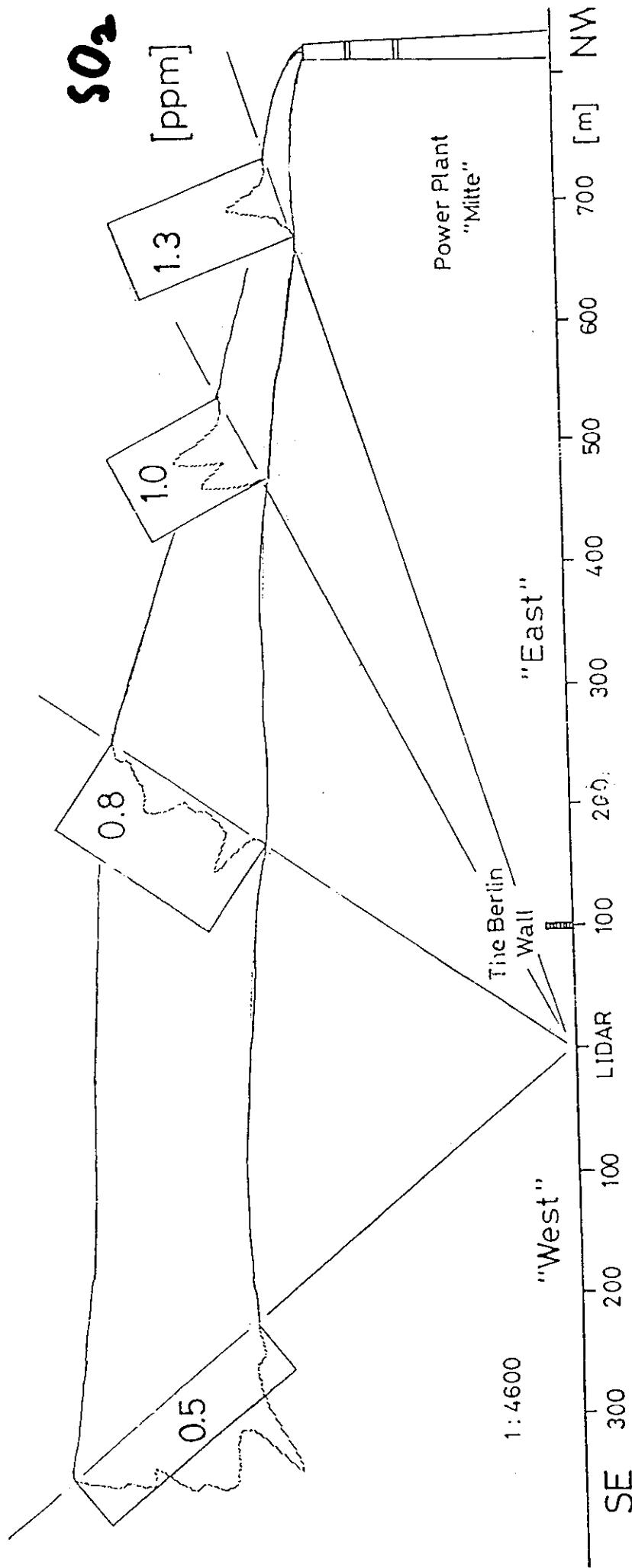
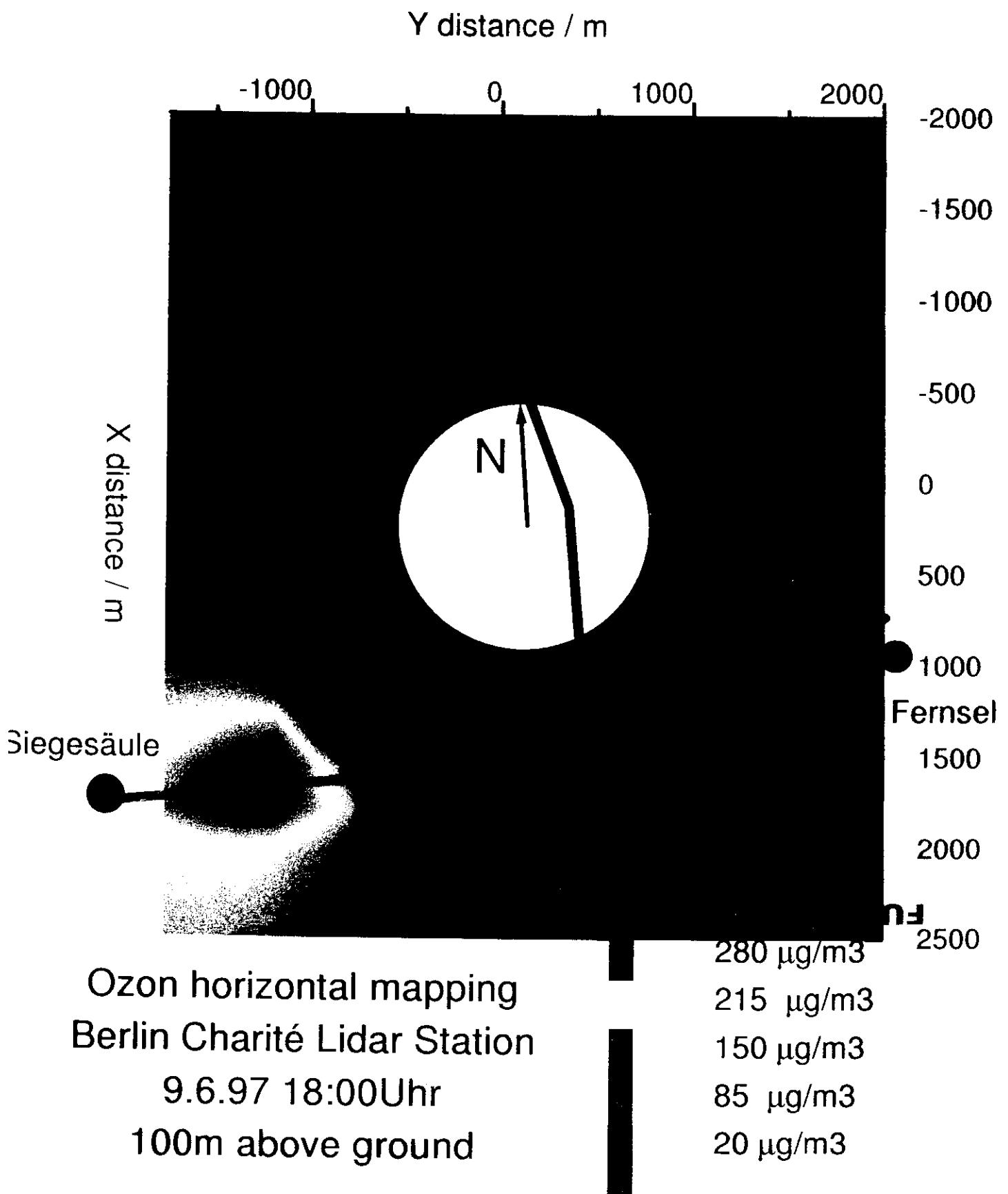


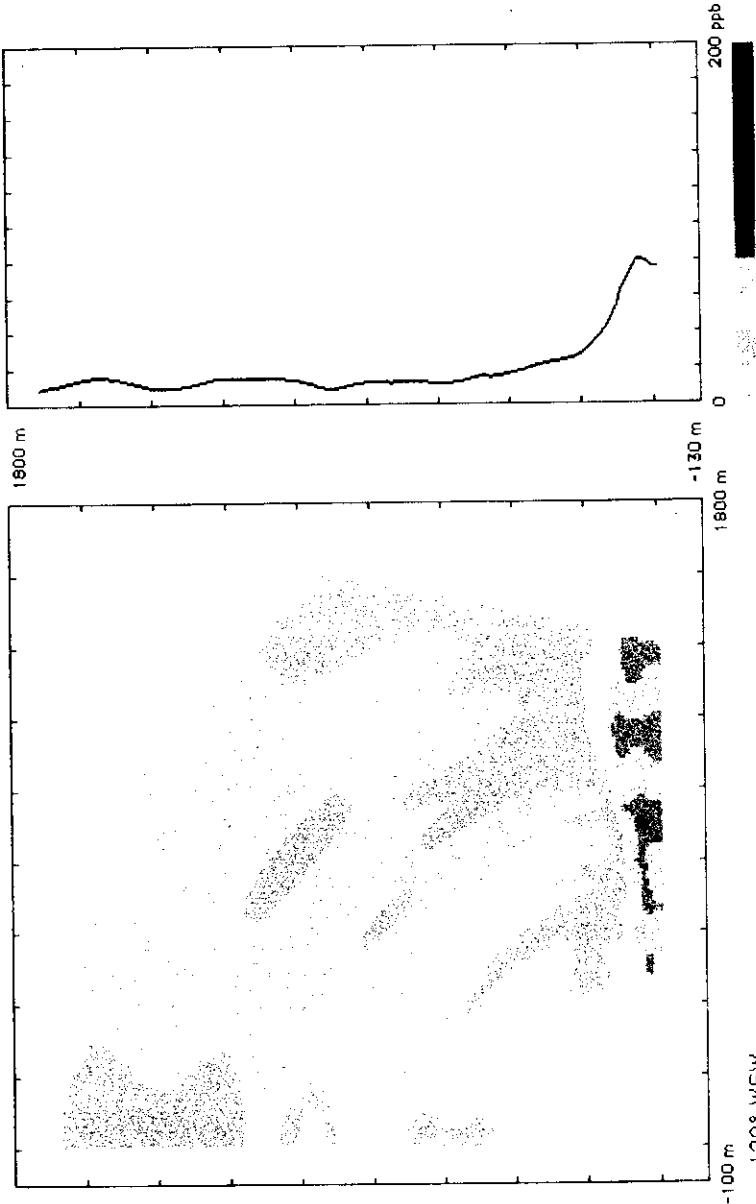
Figure 1: Berlin, power plant 'Mitte' on December 20, 1988 between 15:00 and 21:00 hours MET. Measurement of sulfur dioxide mixing ratios in the plume of the stack. The emission of sulfur dioxide is shown in the graph by the measured backscattered profile inside the plume and the calculated ppm value of sulfur dioxide. Wind direction north-west, wind velocity 2 m s<sup>-1</sup> (Blume), direction of the stack north-west from the LIDAR system.



# Morning Rush Hour in Athens ( $\text{NO}_2$ )

$\text{NO}_2$  Concentration - Vertical Scan  
Athens, Pnyx Hill

14.09.94 09:58-10:06



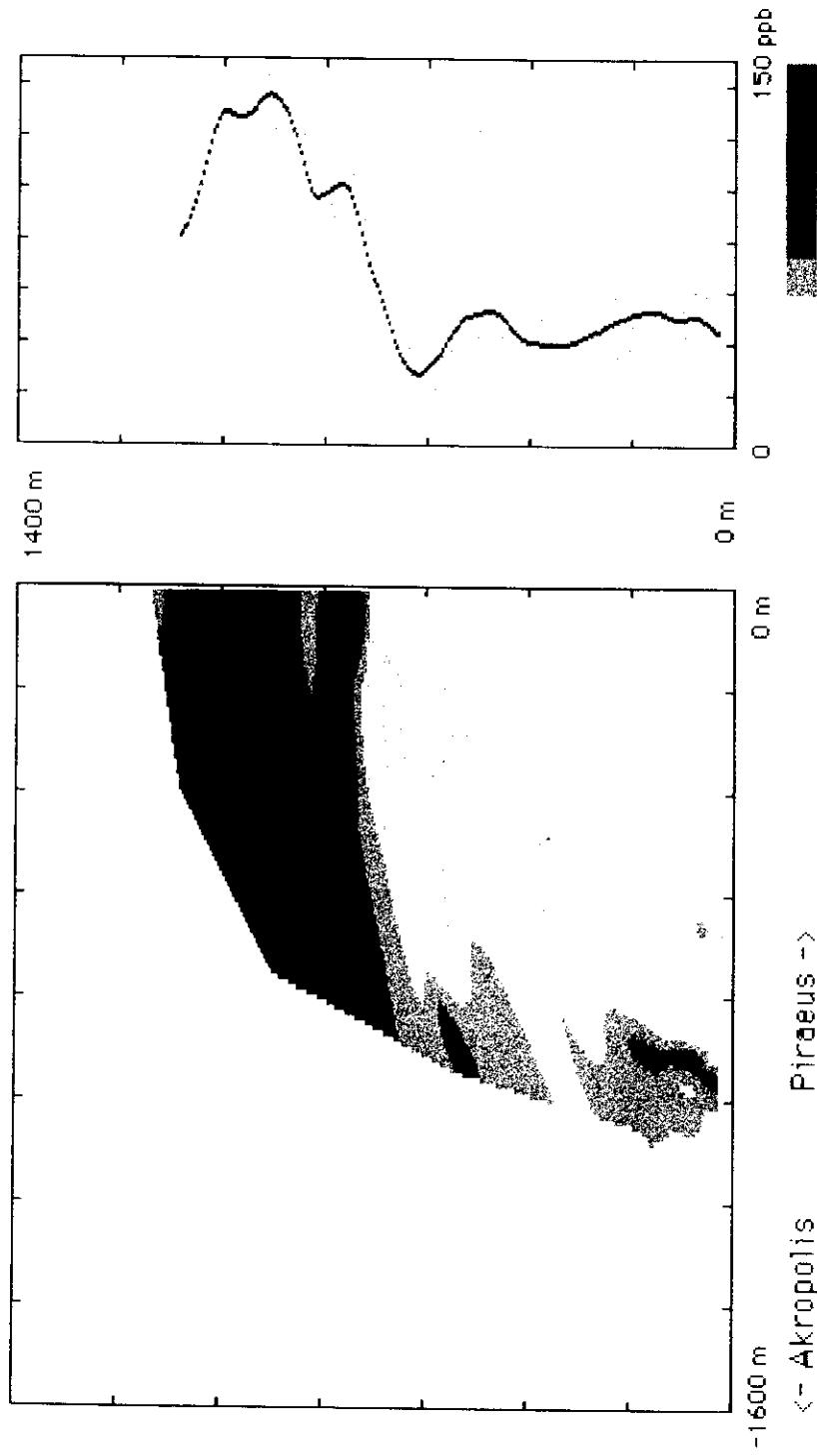
940914.017

ELIGHT Lidar 510M

# Ozone Storage Layer over Athens

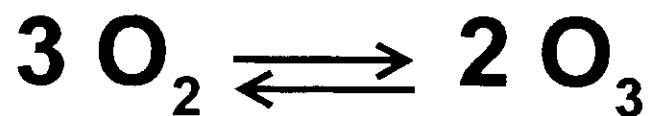
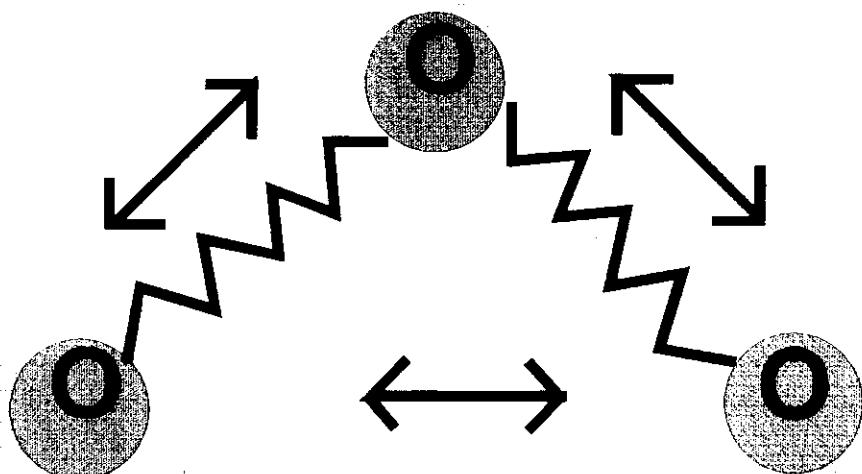
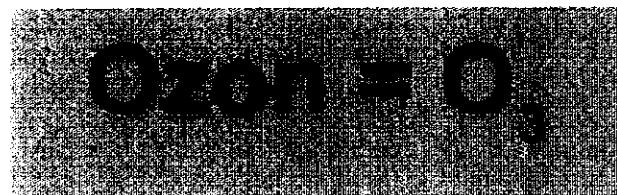
Ozone Concentration - Vertical Scan  
Athens, Phyx Hill

15.09.1994 17:12-17:20



Beispiel einer Lidar Ozonmessung während einer Sommersmogepisode in Athen (mobiles Lidar, Elight Laser Systems). In etwa 1000 m Höhe ist eine sog. Ozon-Speicherschicht zu erkennen.

Riesenfeld und Schwab 1922:



$$\Delta H = 34,2 \text{ kcal/mol}$$

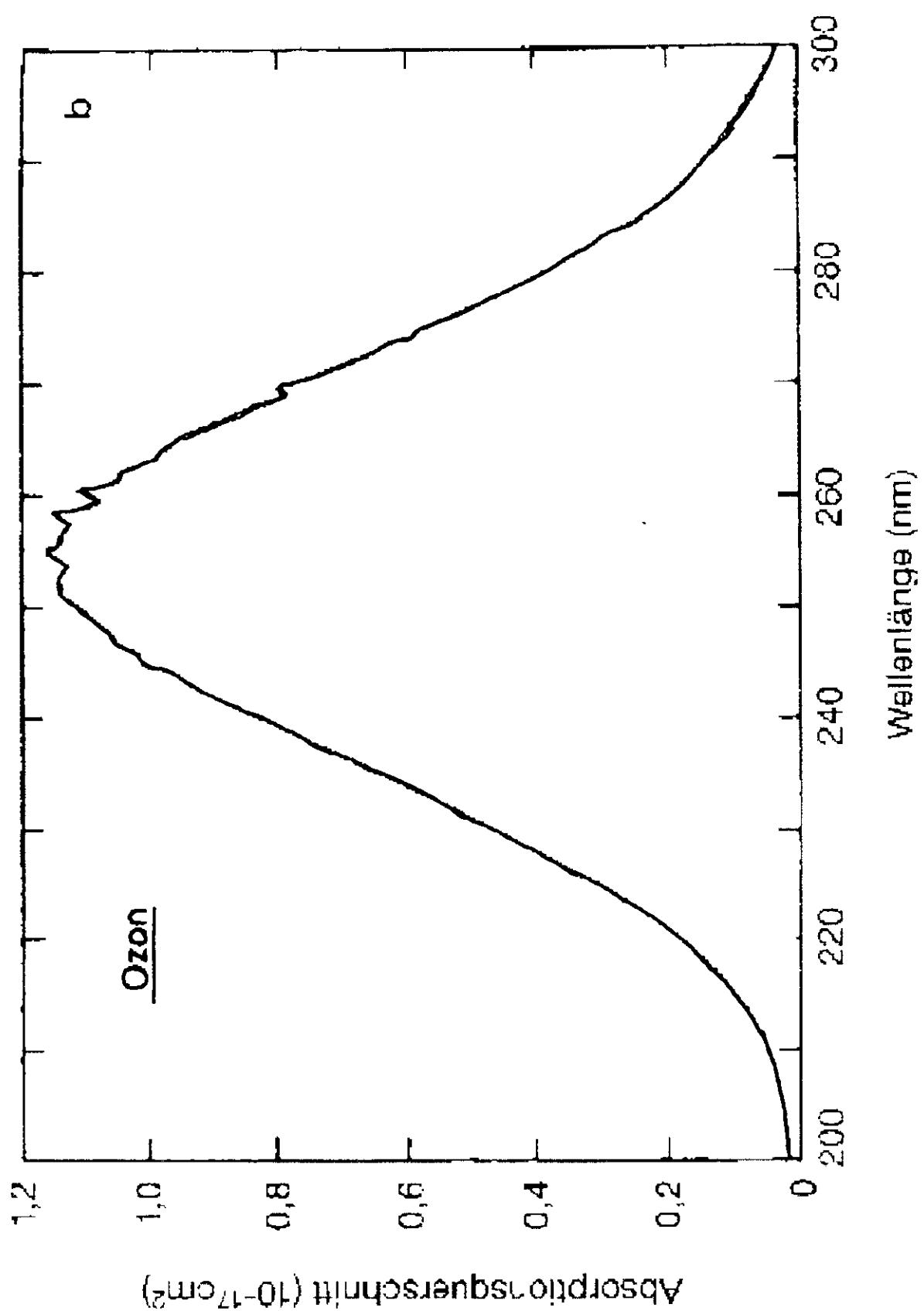
## Properties of Ozon

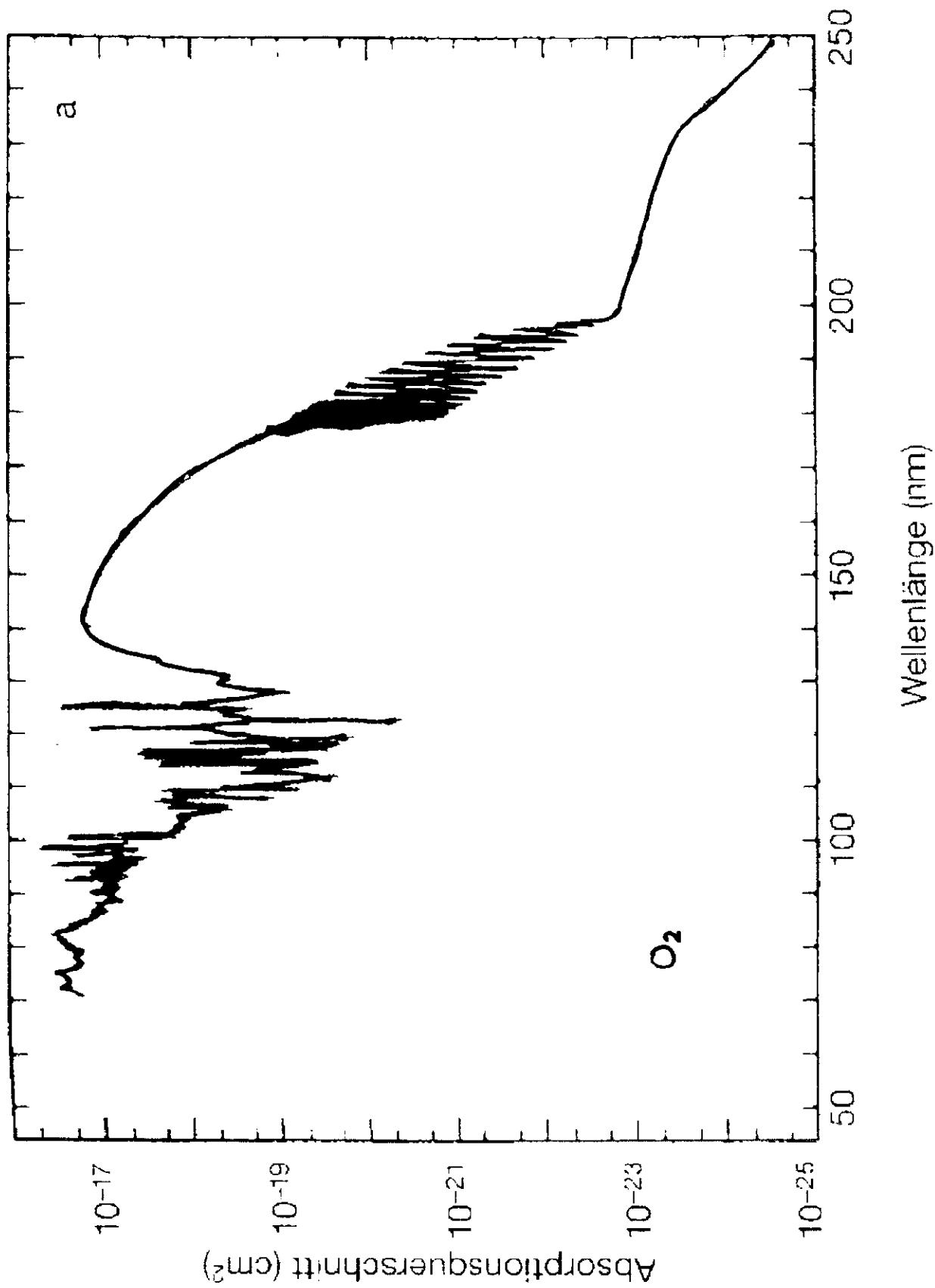
- purple solid or liquid, invisible gas
- melting point - 192,7 °C
- boiling point - 111,9 °C
- strongest oxidizer after Fluor
- strong UV-absorber
- oxidizes fat-acids
- damages cell walls
- attacks the central nerv system
- damages plants and trees
- magnificent disinfectant

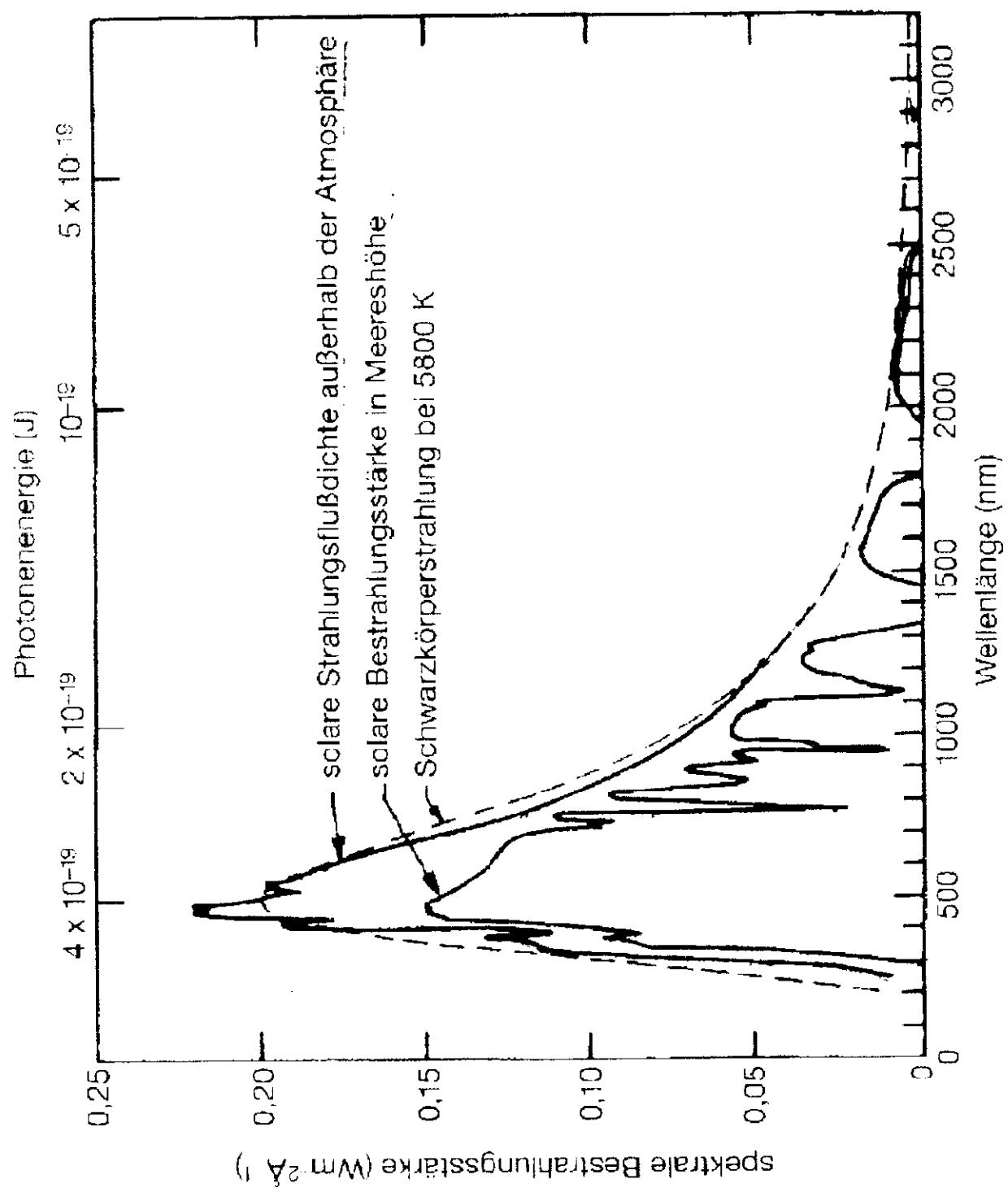
Max admitted limit values

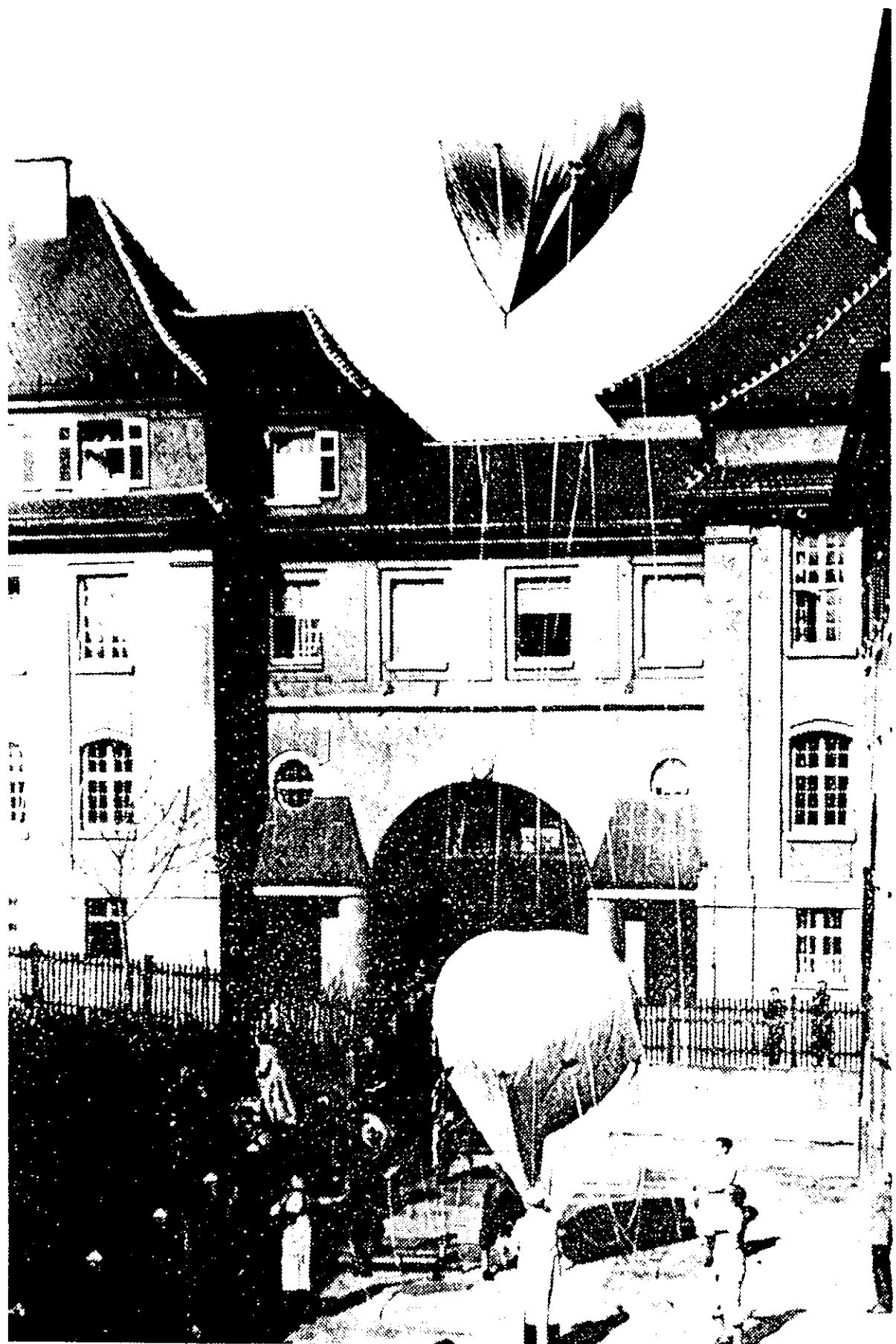
150 µg / m<sup>3</sup> air (1/2 h)  
(~66 ppb)

50 µg / m<sup>3</sup> air (24 h)  
(~22 ppb)



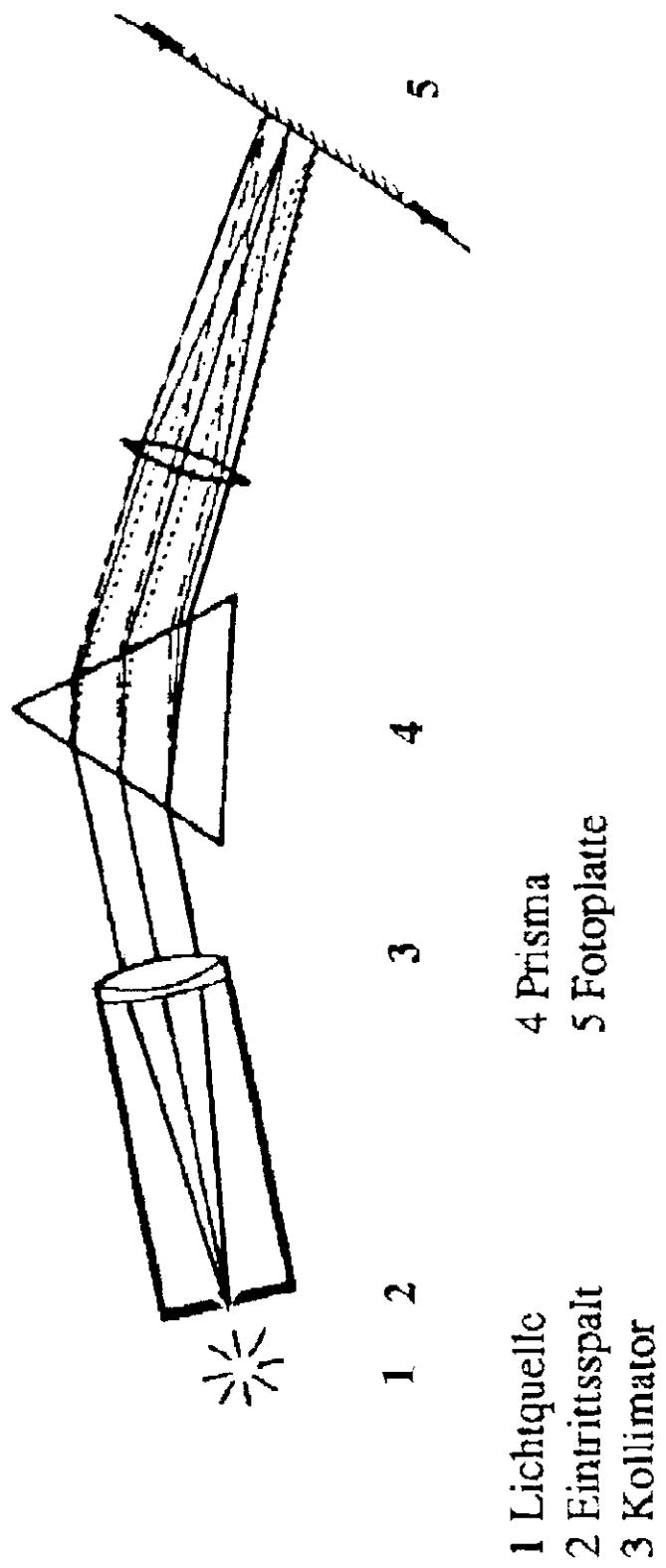


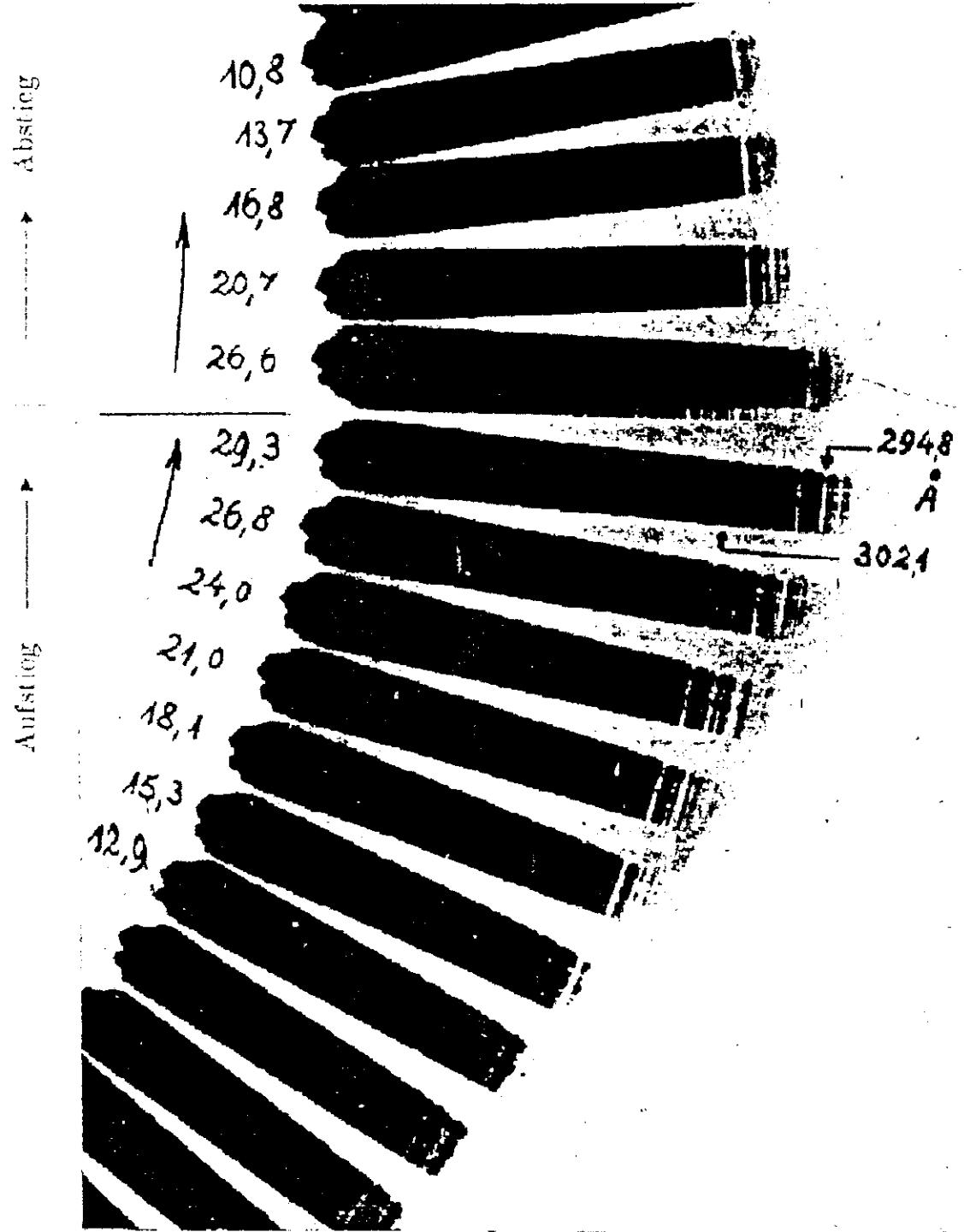




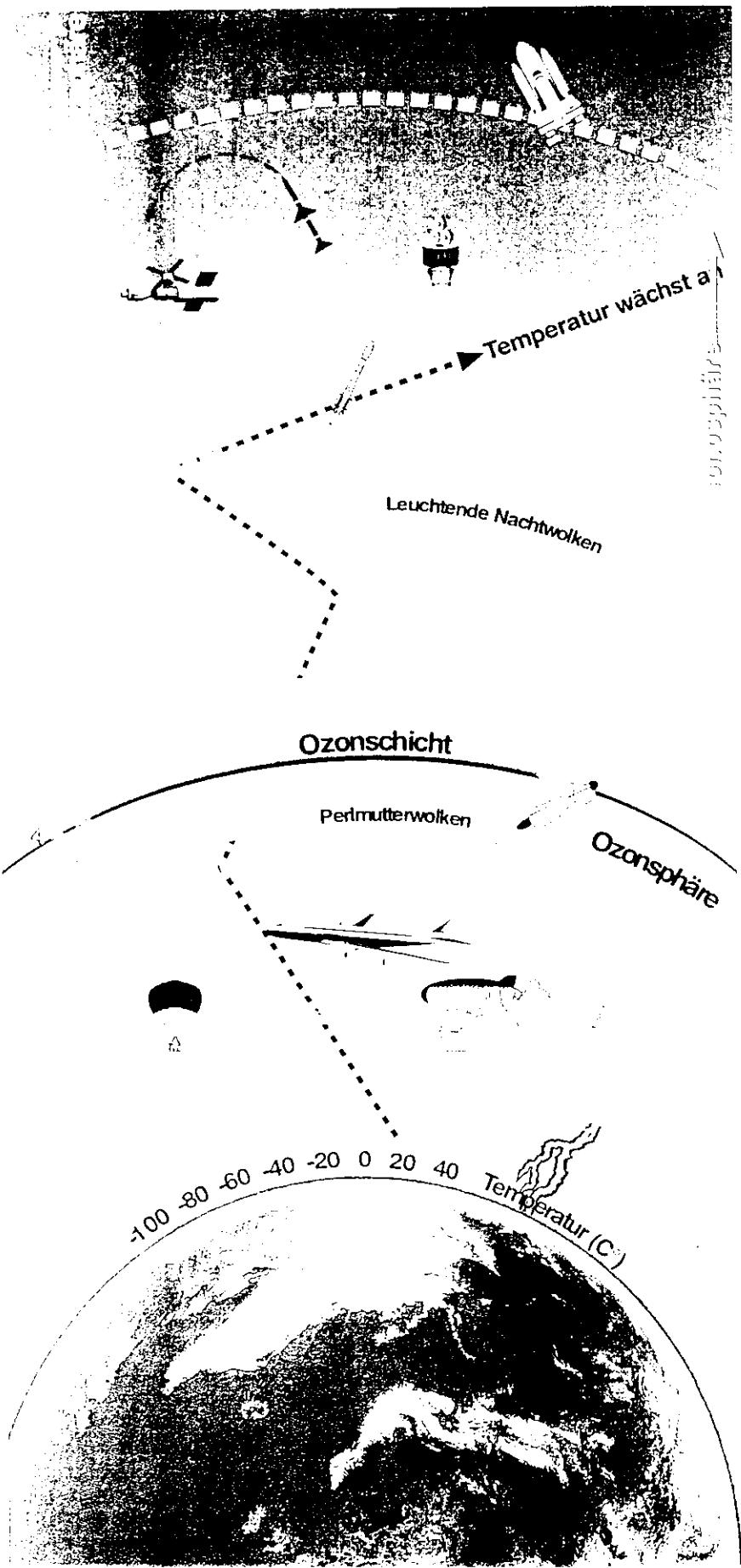
Ballonaufstieg vom Institut in Stuttgart aus

# SPEKTROGRAPH





E. Regener  
1881-1955

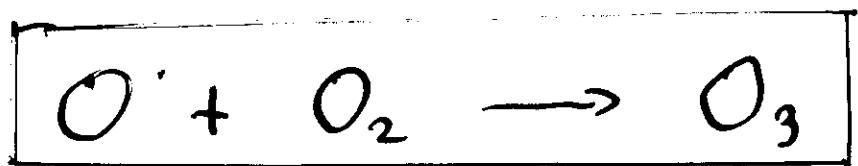


# Stratospheric Ozone Formation (Chapman)

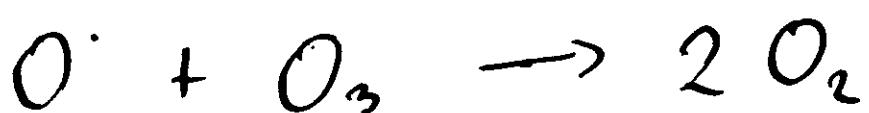
---



(1300 Å < λ < 2400 Å)



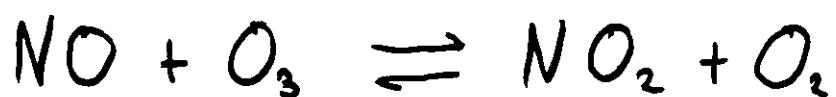
Backreactions :



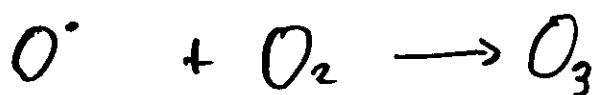
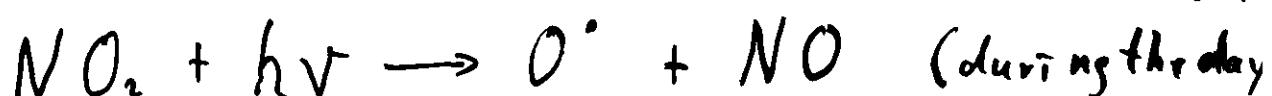
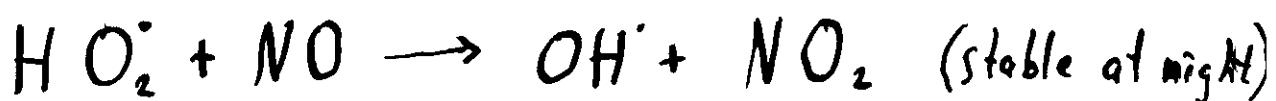
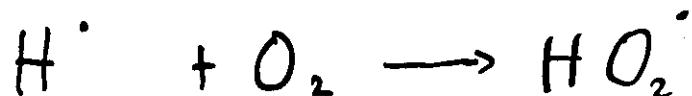
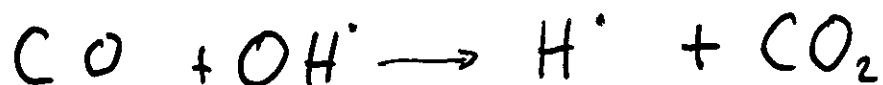
# The Chemistry of Ozone in the Troposphere

---

## 1. Leighton Relation



## 2. At high NO-Concentrations:

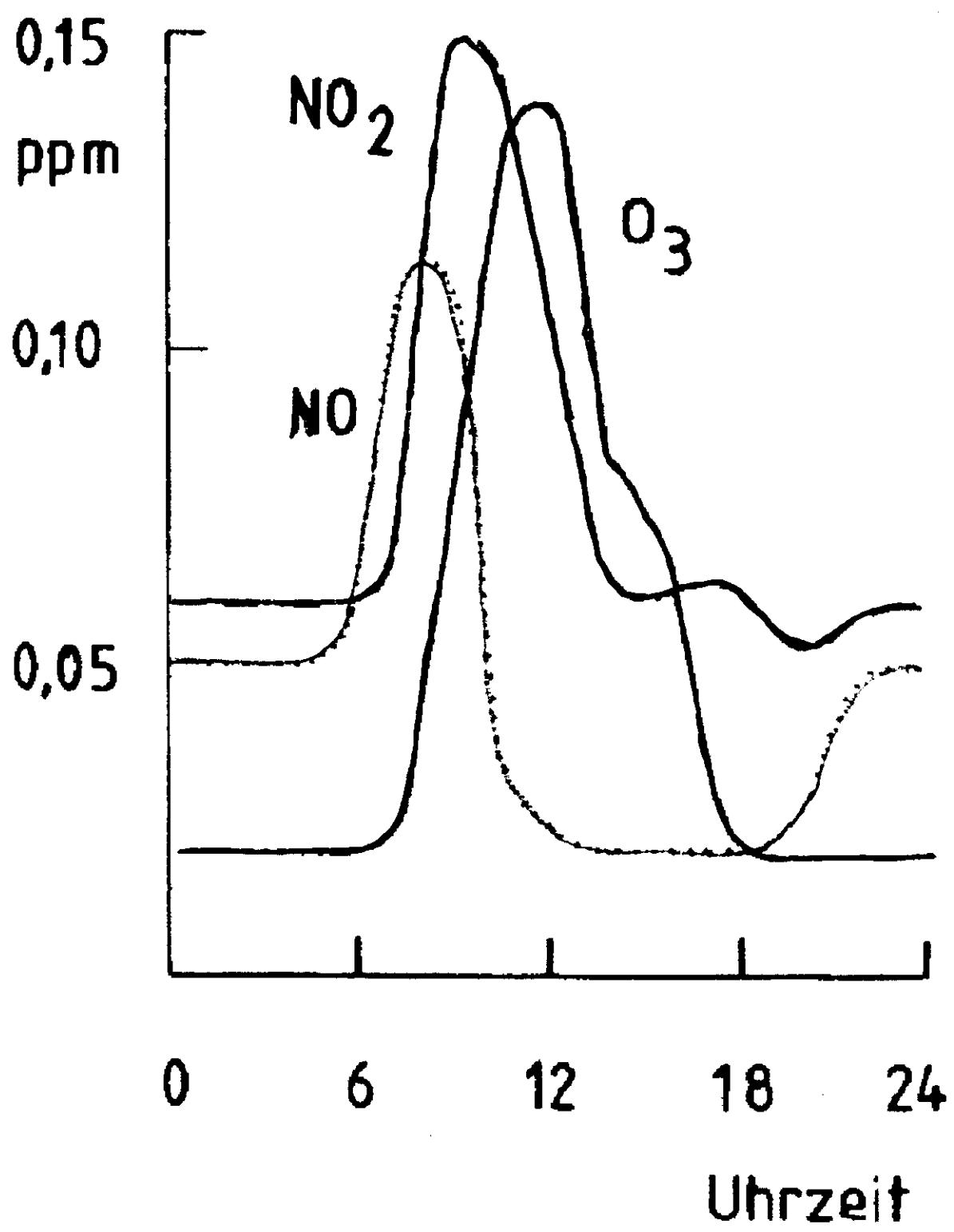


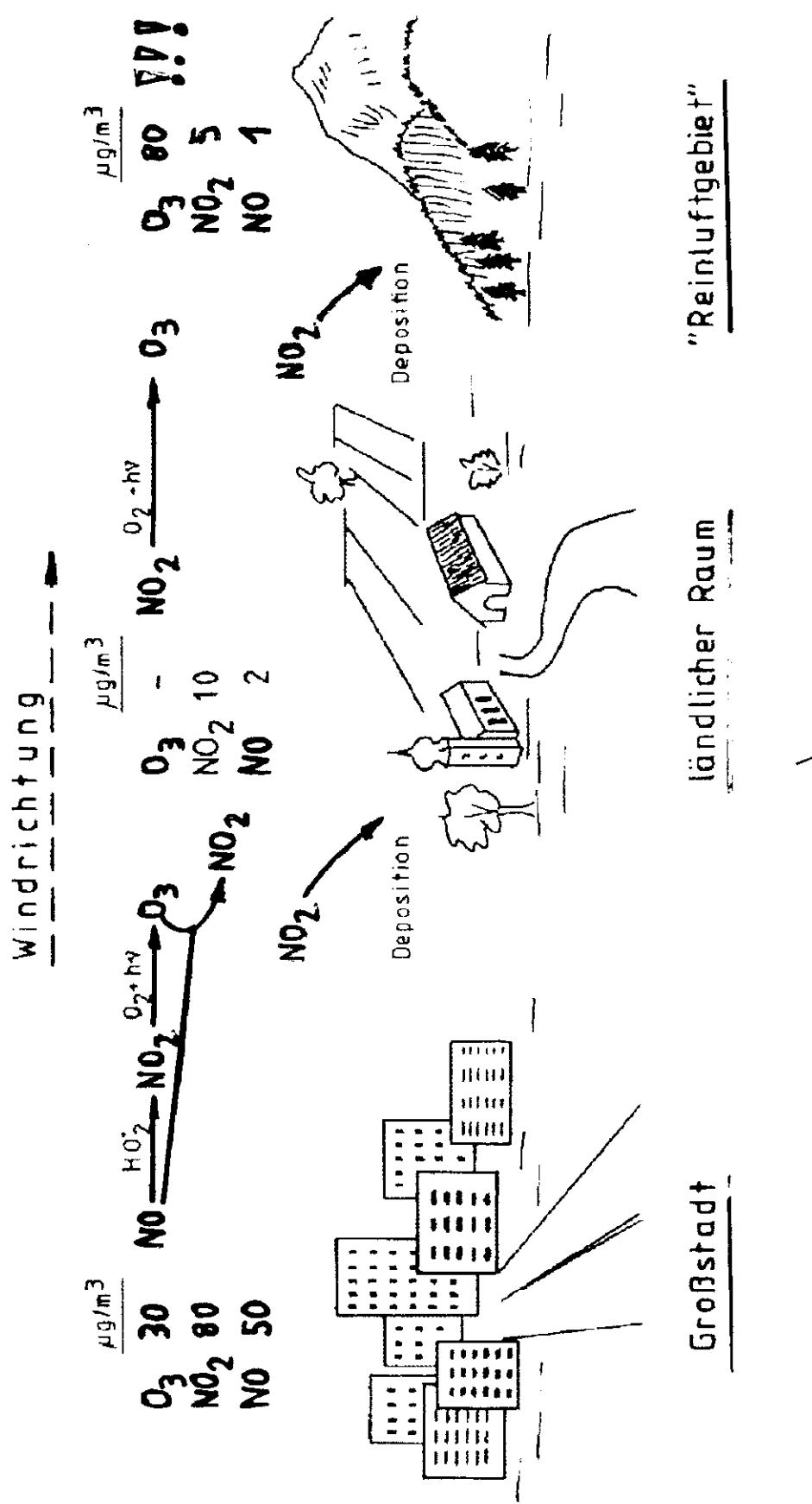
## 3. In the presence of arom. hydrocarbs:



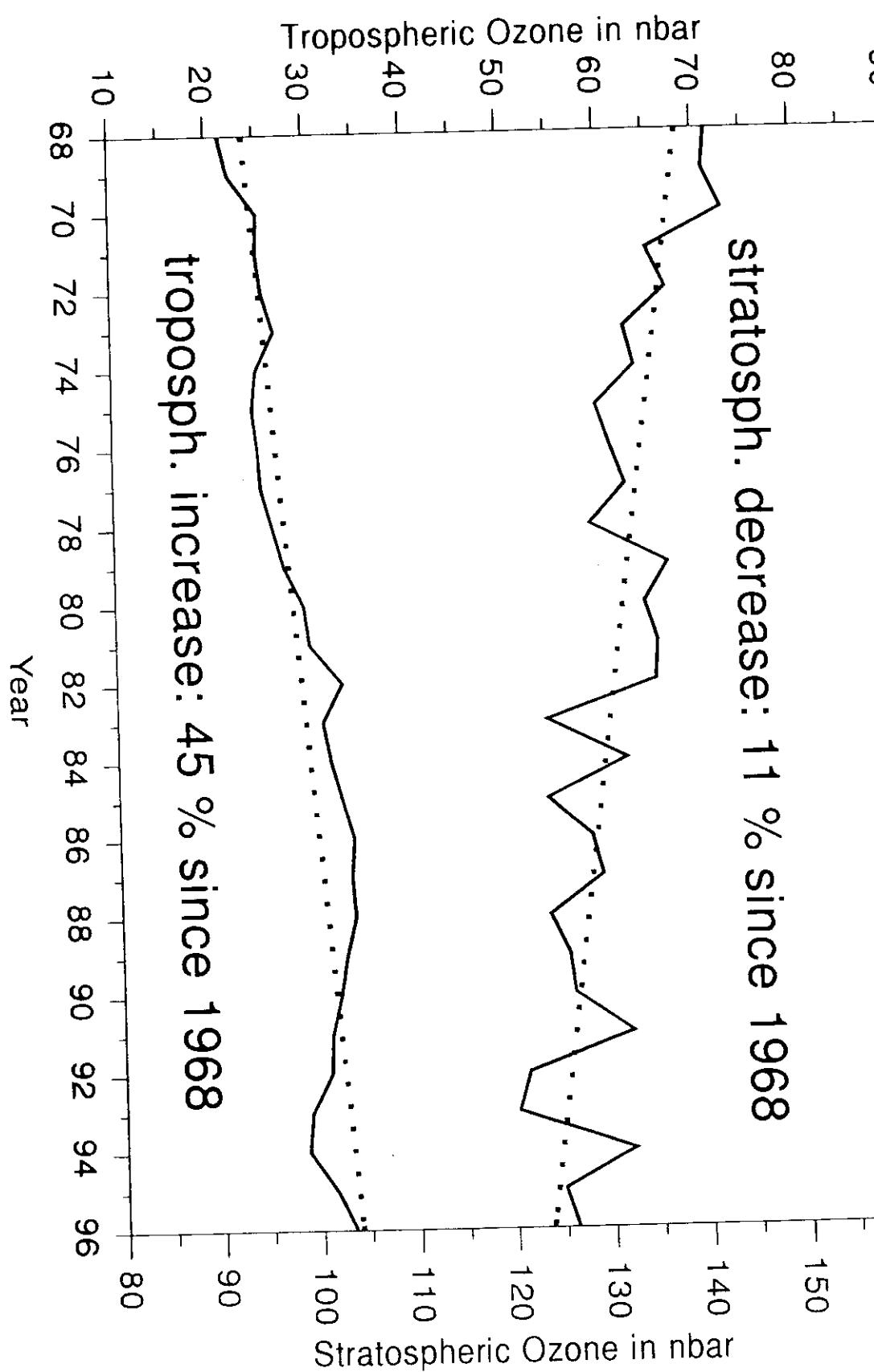
Formation of toxic Aldehydes

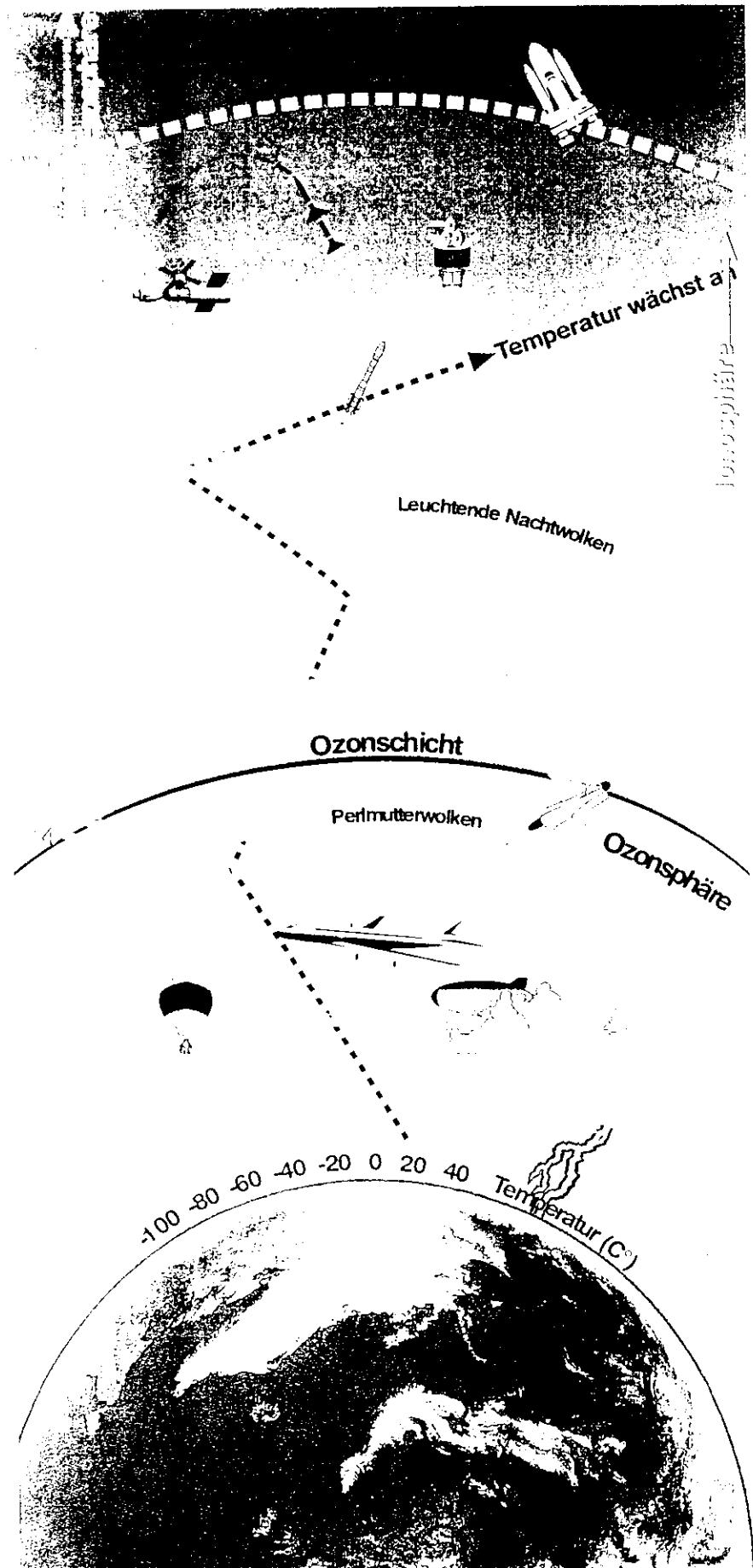
Formation of Ozone



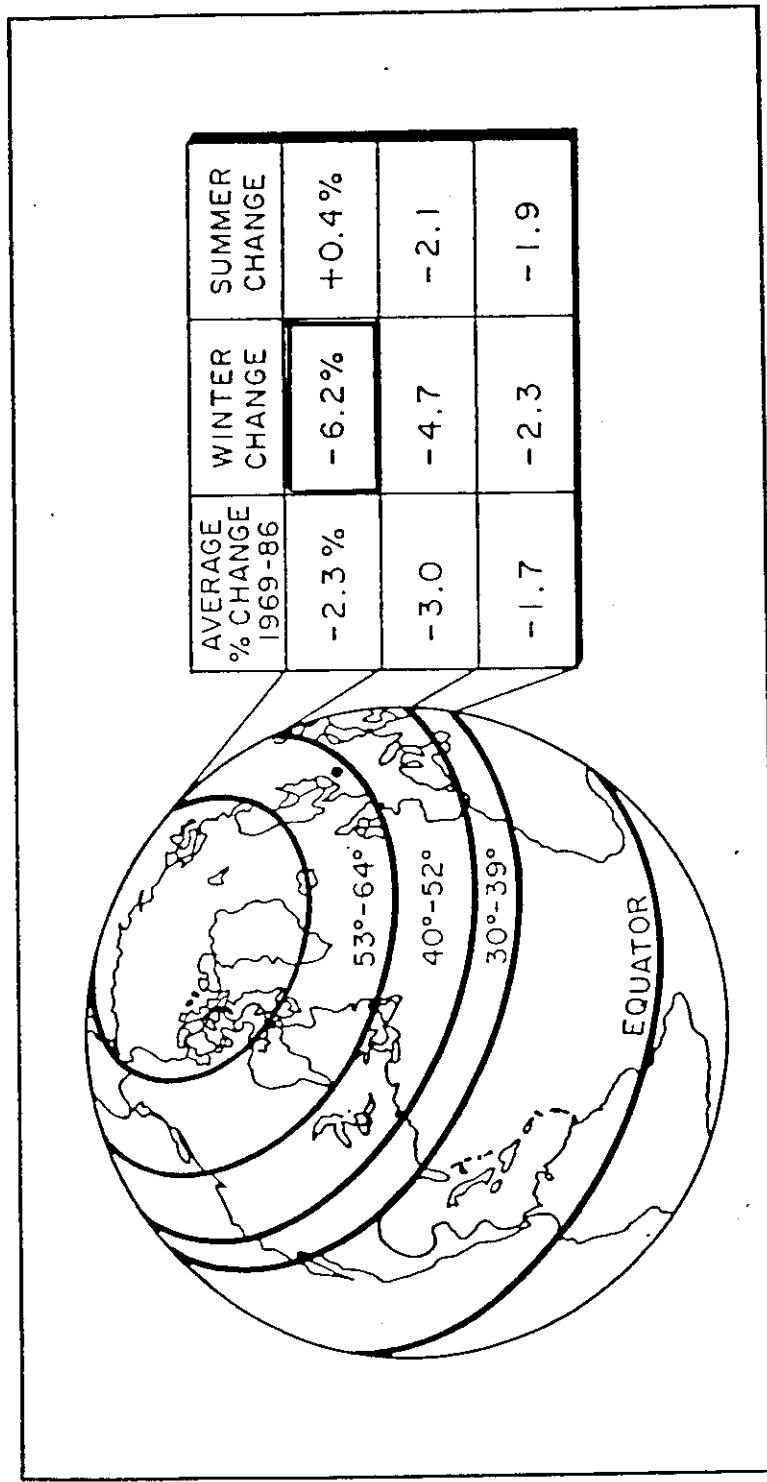


Ozon am Hohenpeissenberg (DWD)

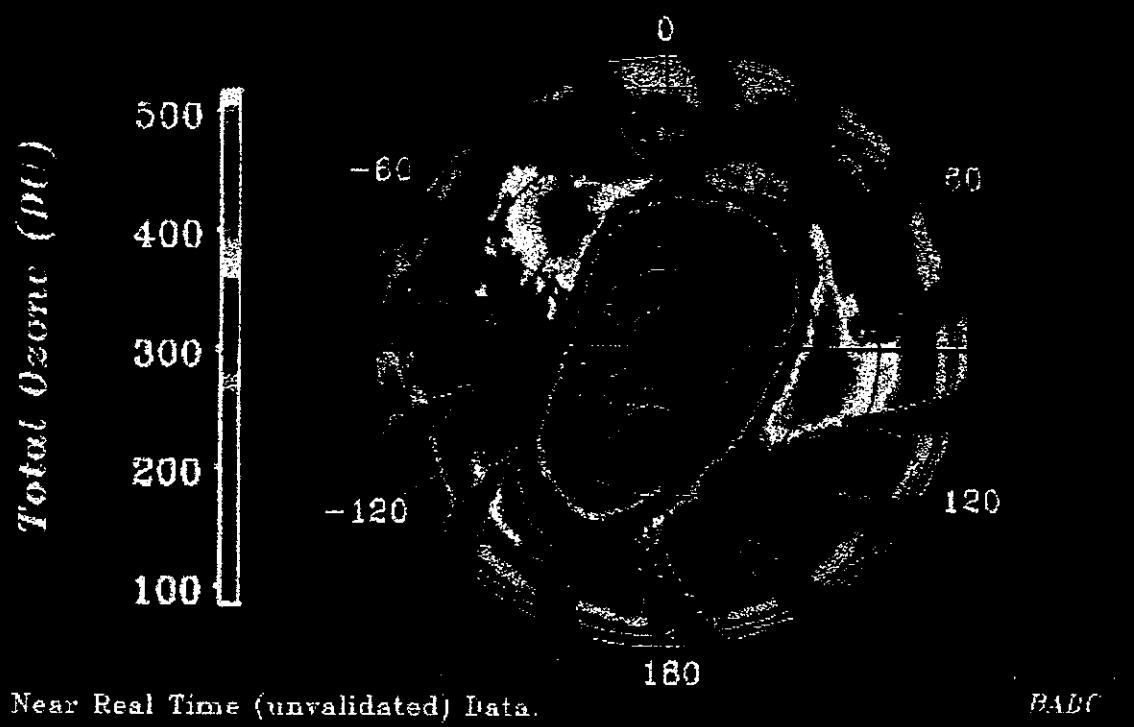




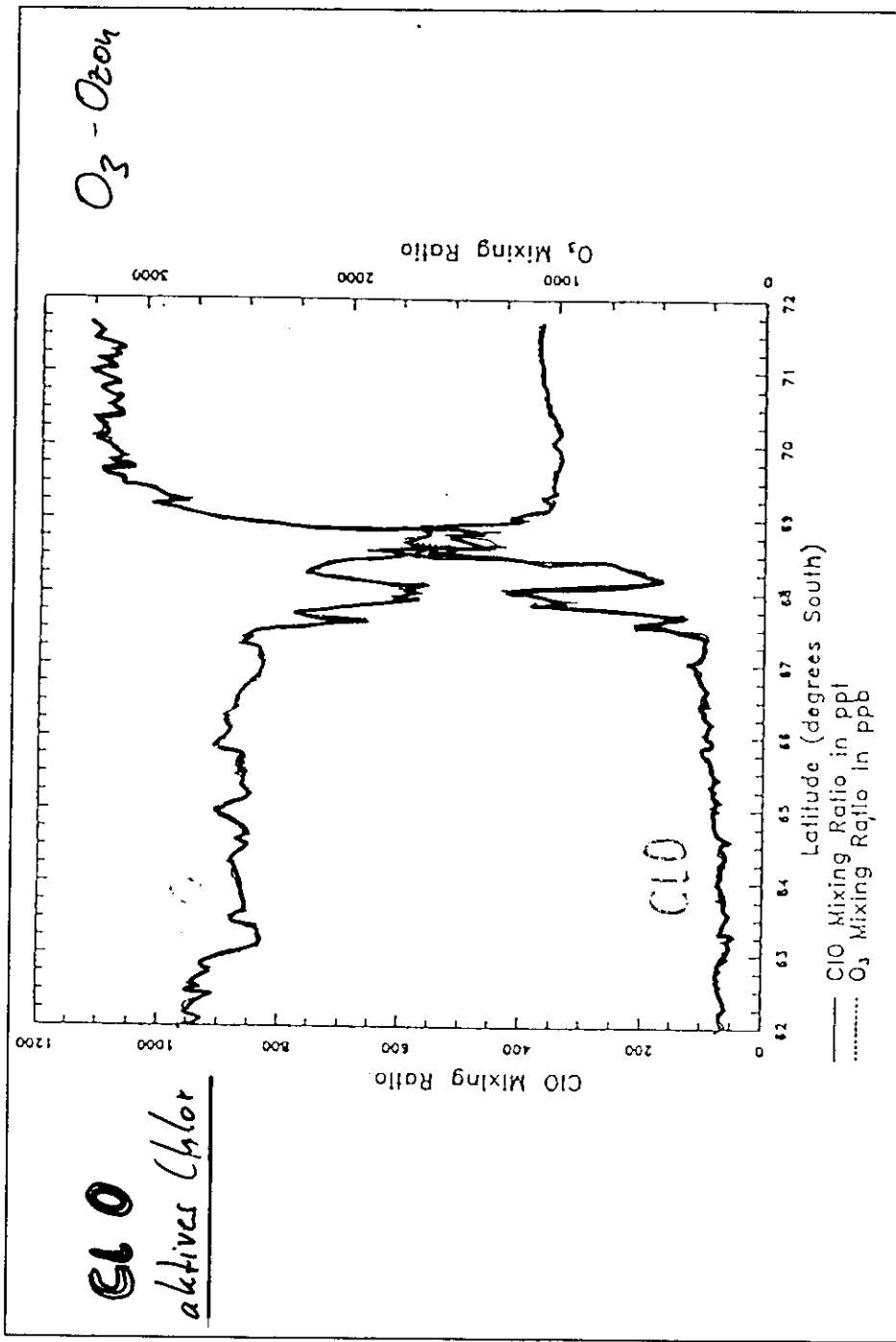
## Ozontrend in der Arktis und in mittleren Breiten



Ear Probe TOMS total ozone 18-Sep-1997  
Southern hemisphere, orthographic projection

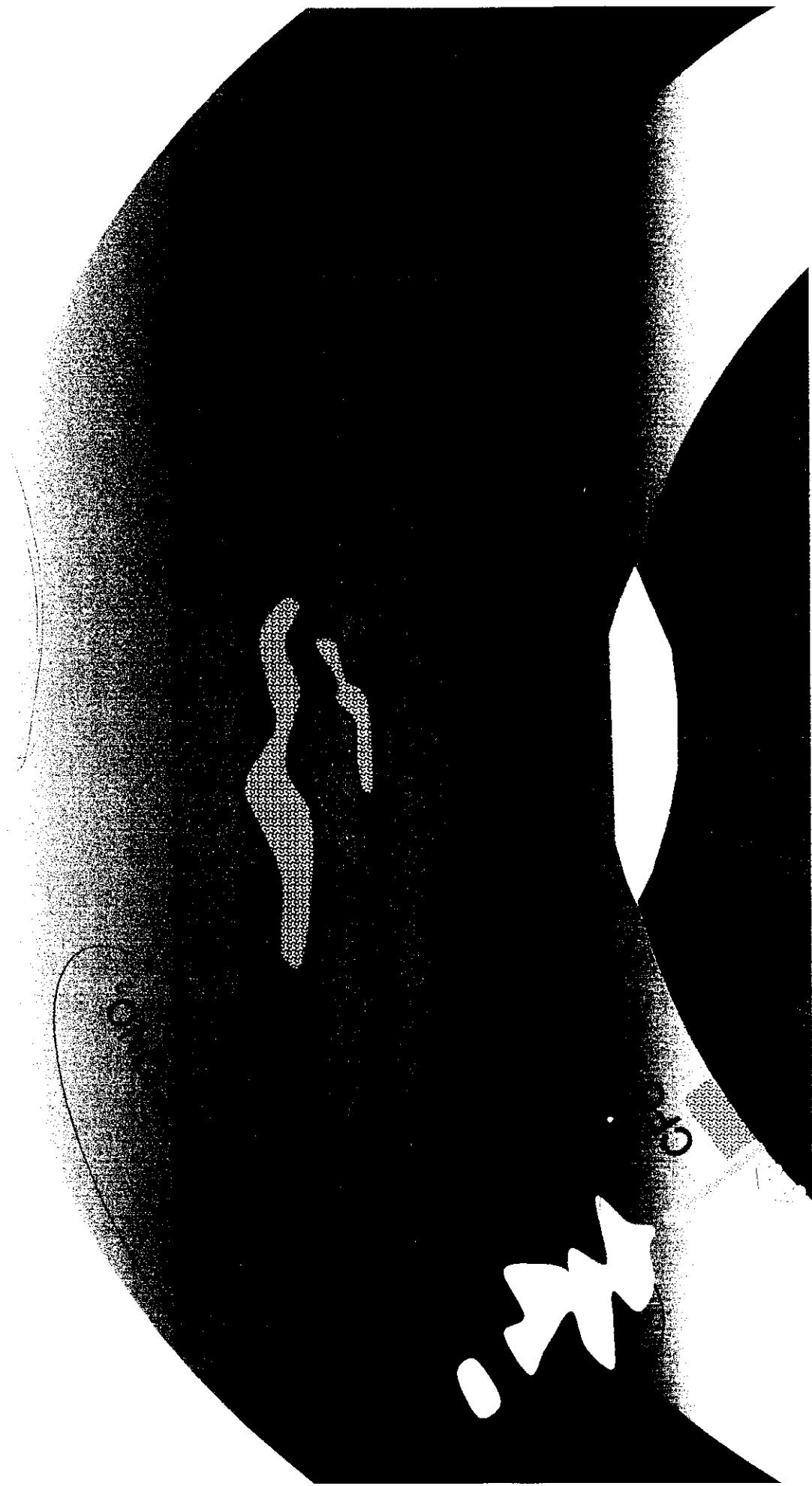


Hinweis auf anthropogenen Ursachen des Ozonlochs:  
Antikorrelation von ClO und Ozon

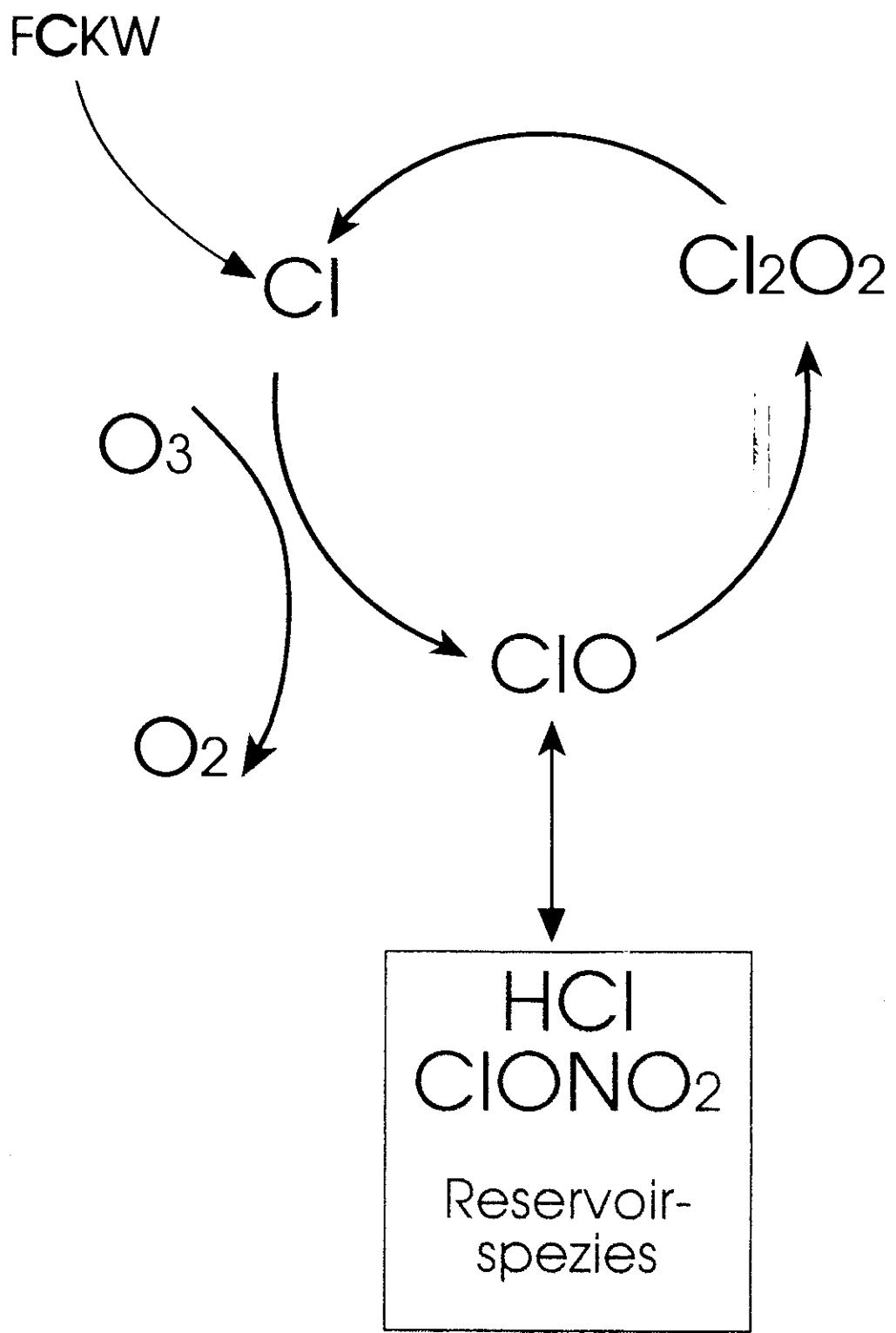


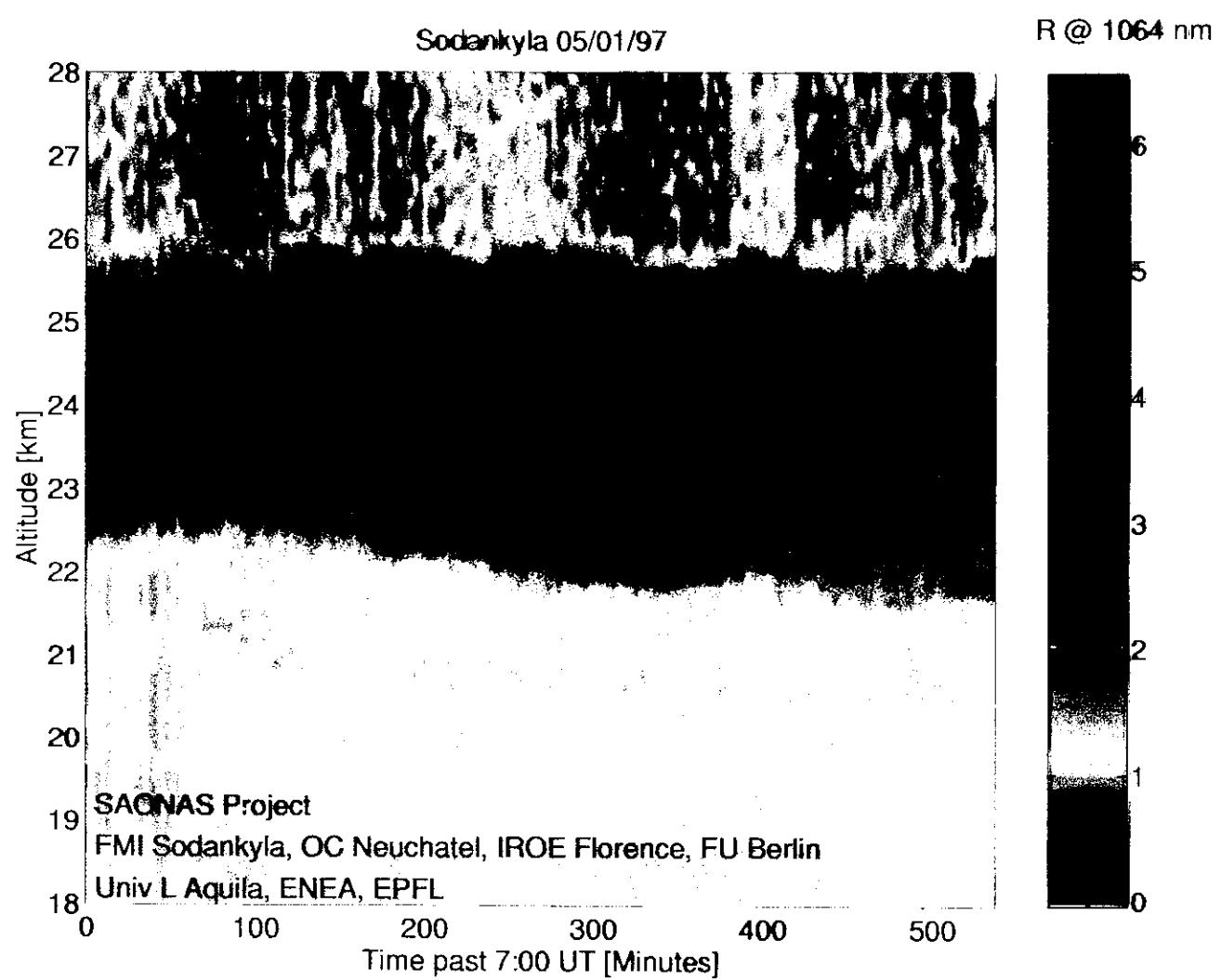
Anderson et al. 1989

## Polar Ozone Depletion



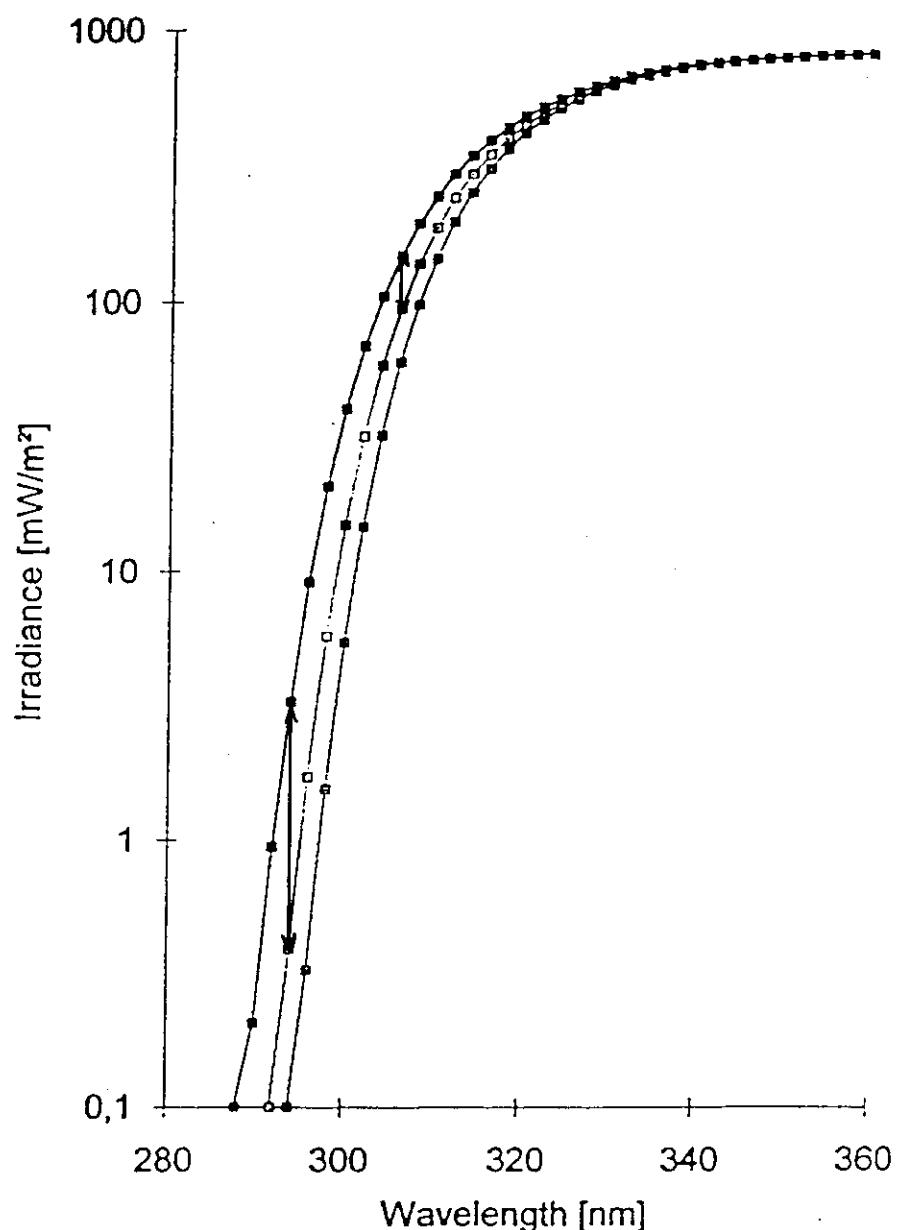
# Zyklischer Ozonabbau





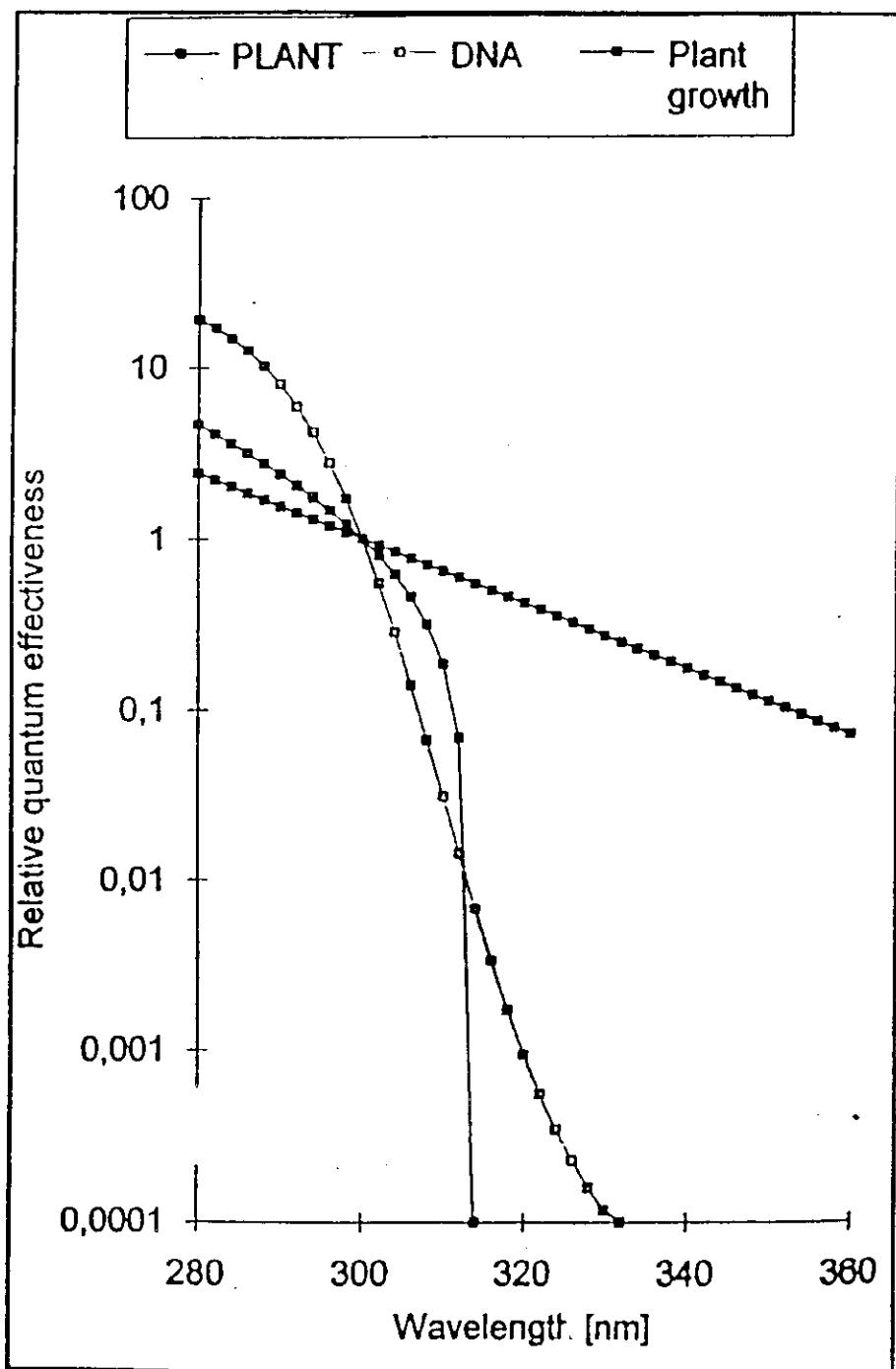
## Zunahme der UV-Strahlung mit abnehmender Ozonschicht

—●— 360 Dobson —○— 270 Dobson —■— 180 Dobson

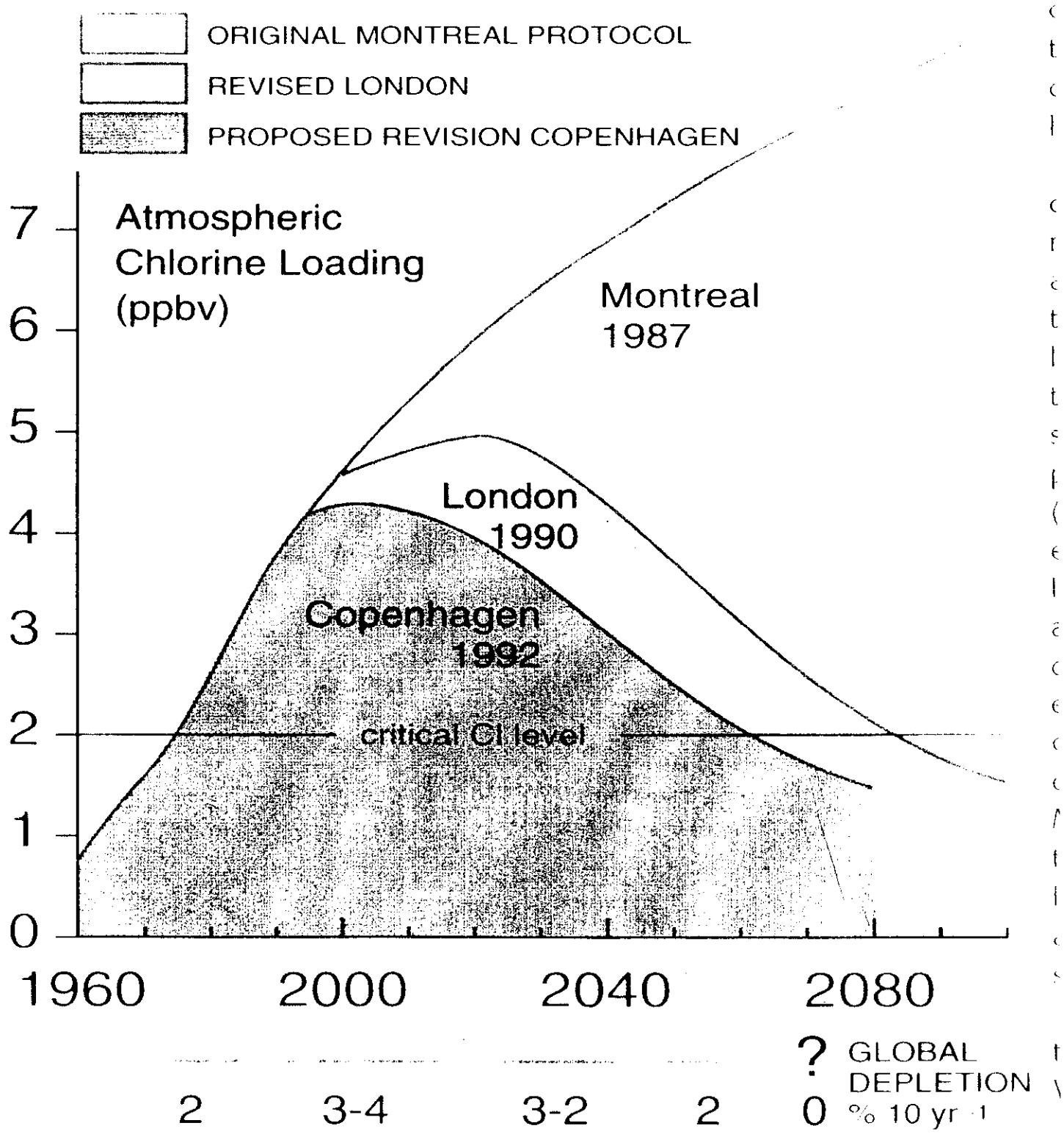


UV-Strahlungsstärke (Ozonschichtdicke) =  
Extraterrestrische Strahlungsstärke •  $e^{-k \cdot \text{Ozonschichtdicke}}$

# Wellenlängenabhängigkeit für DNA- und Pflanzenschädigung durch UV

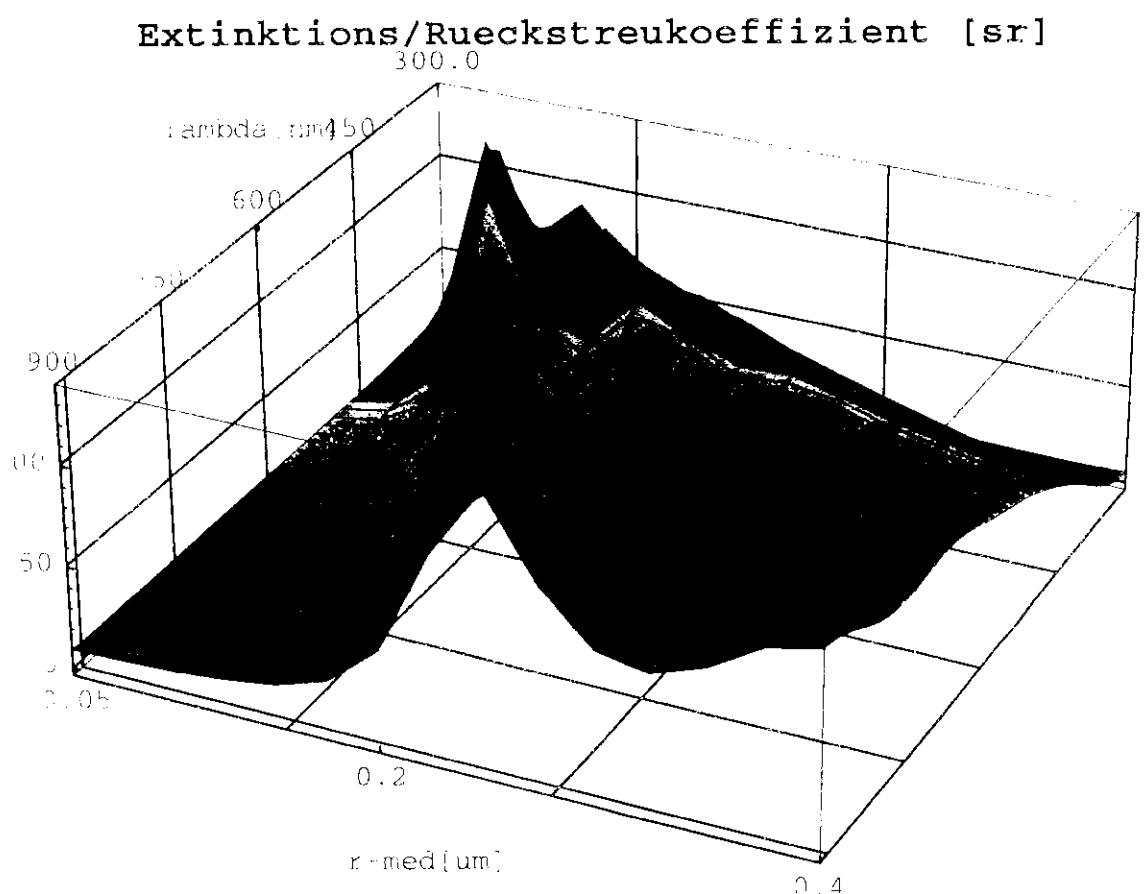
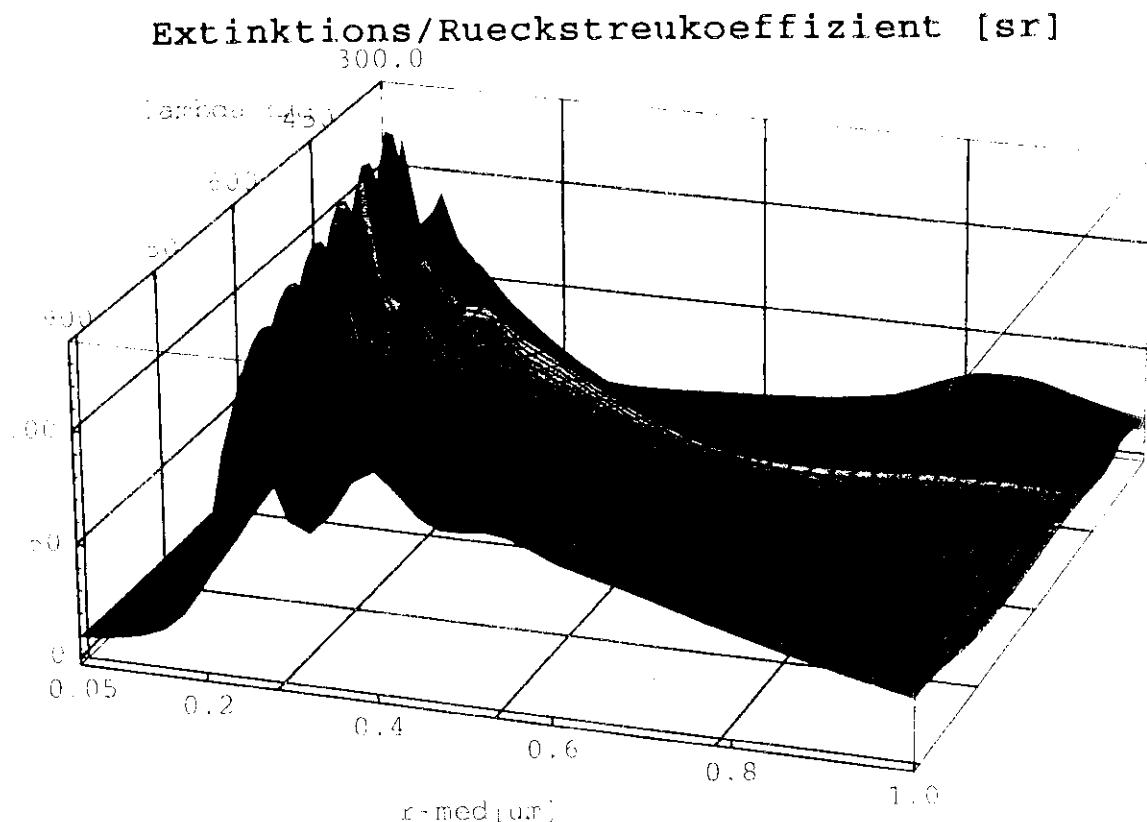


Montreal Protocol are observed.

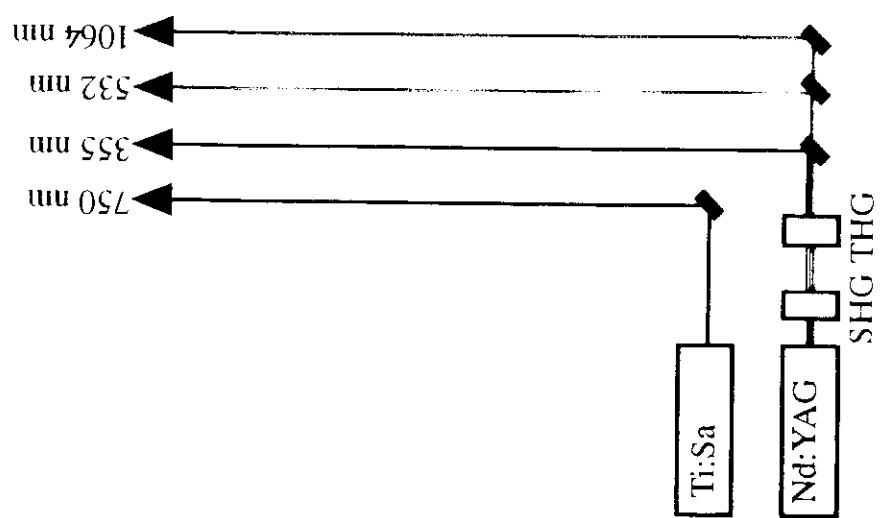
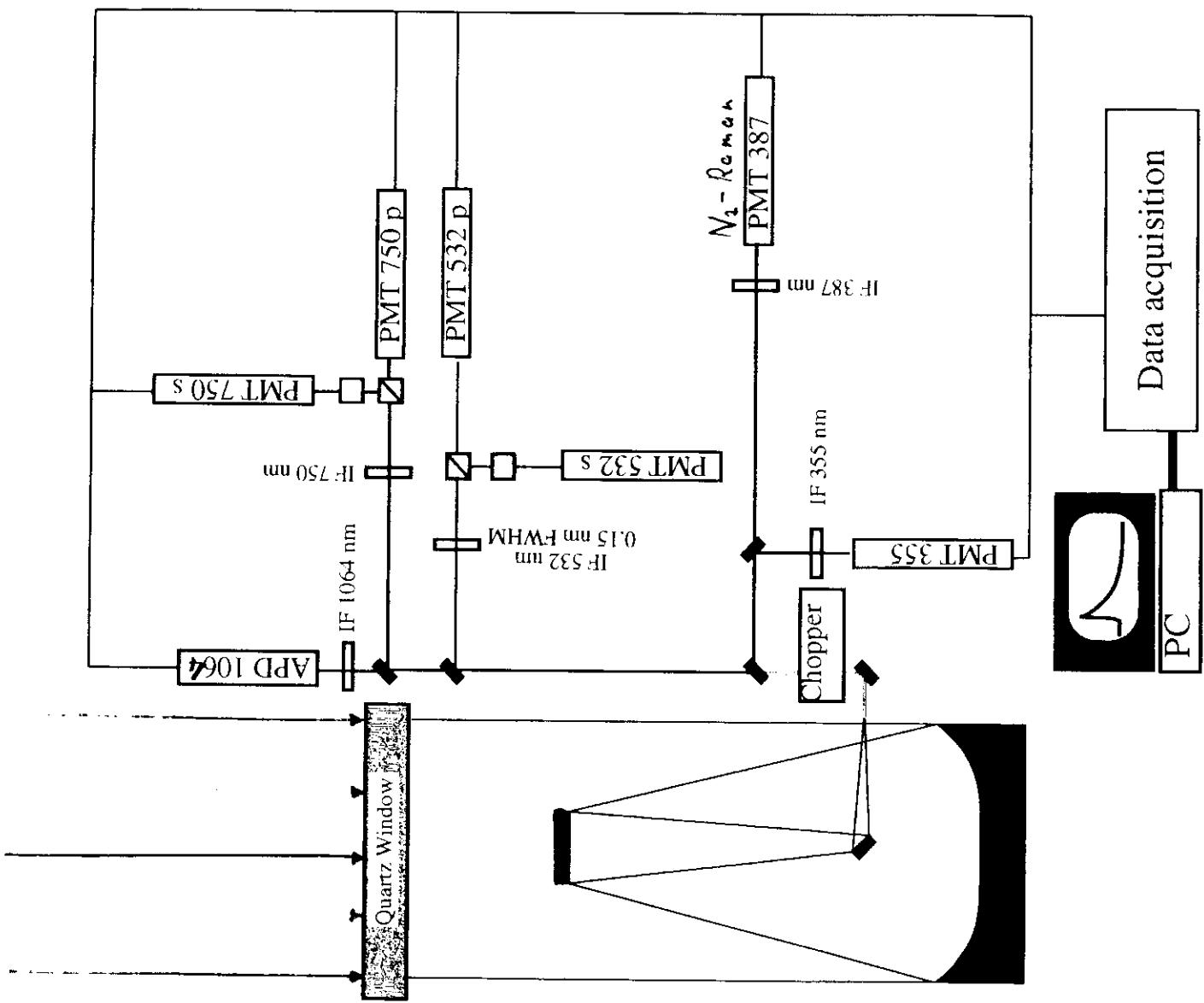


## Spektrales Verhalten von lognormalen Größenverteilungen

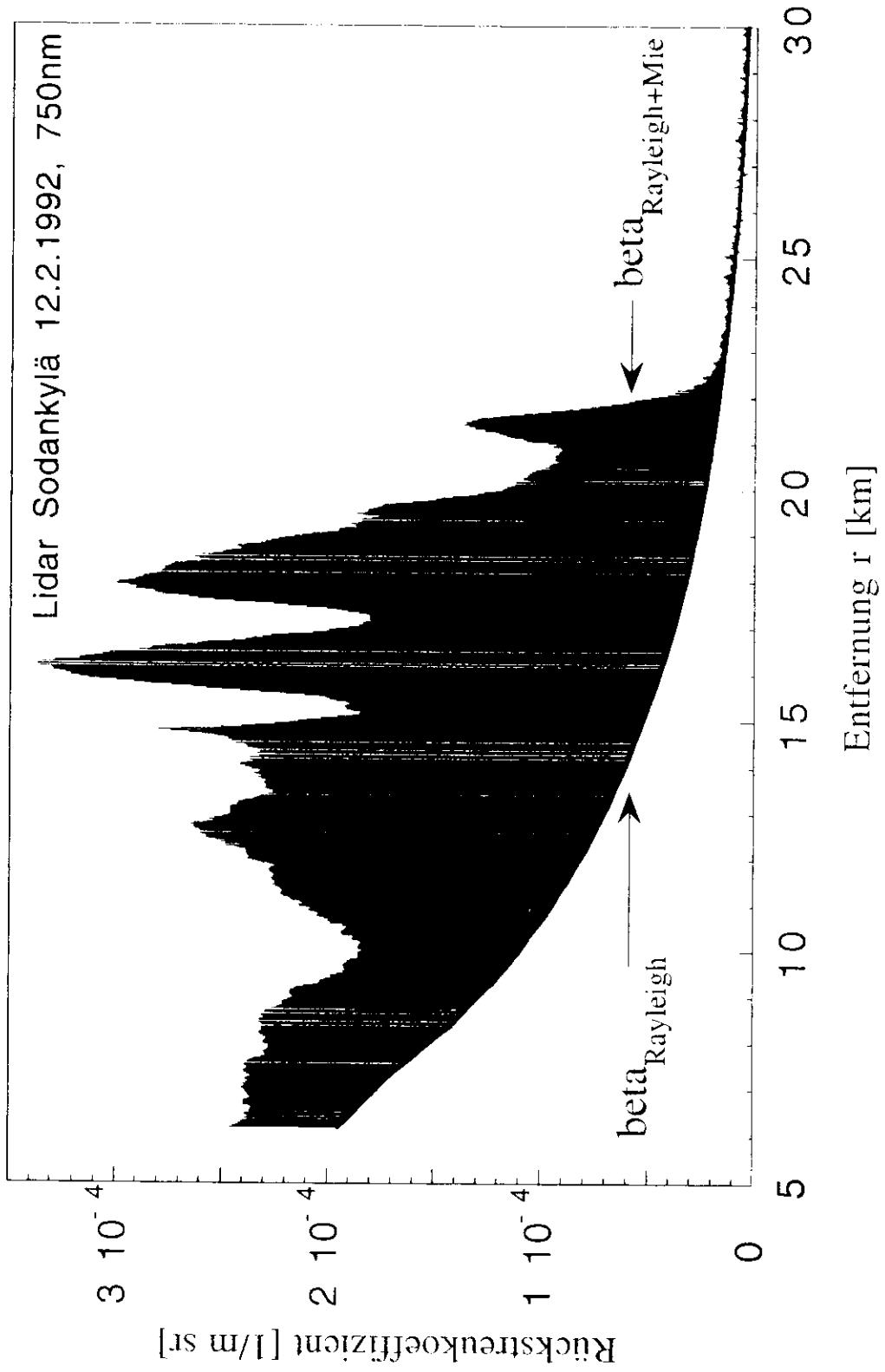
$\sigma=1.105$  (Breite=0.1 \* r-mean)



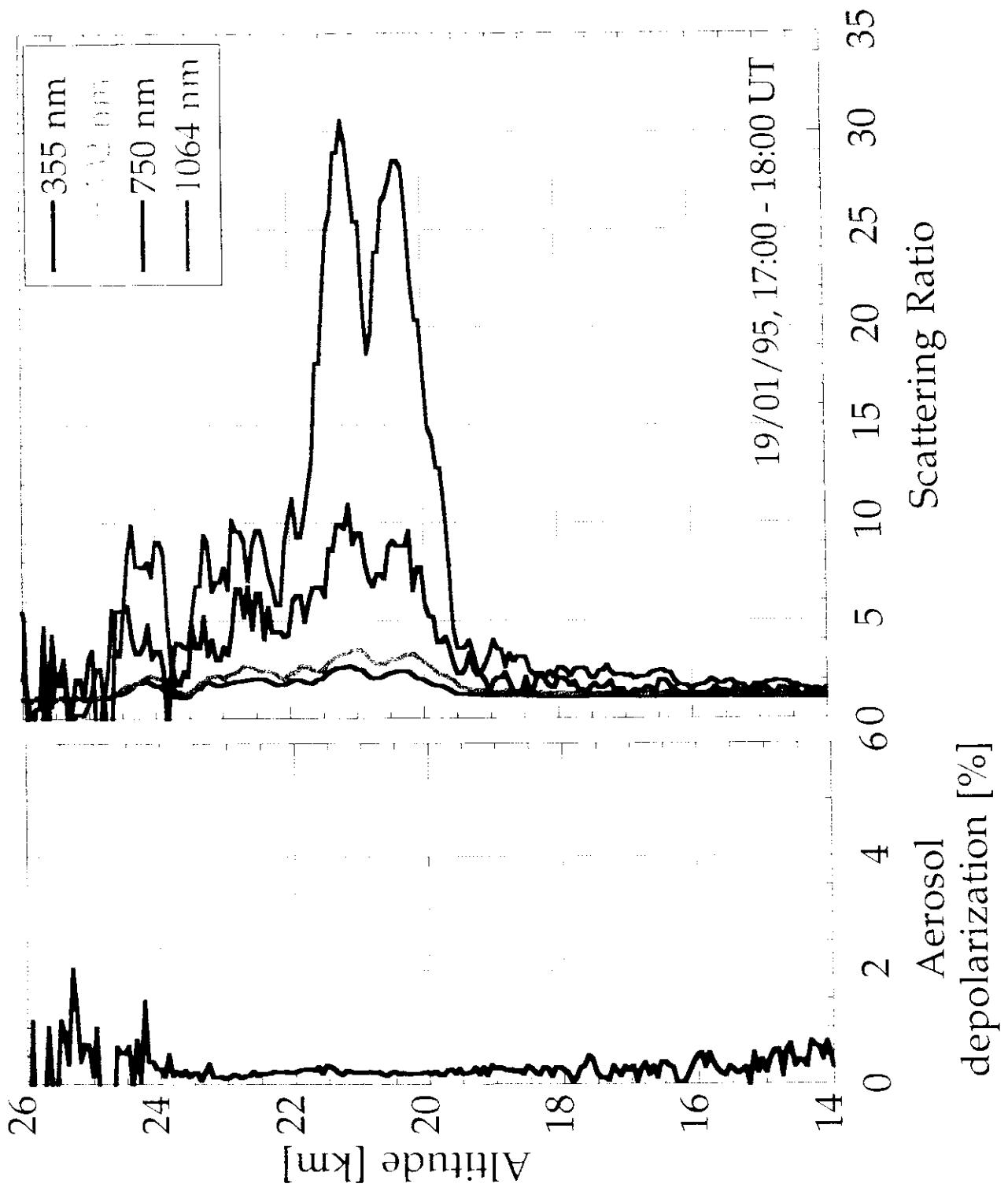
# Sodankylä Lidar Setup



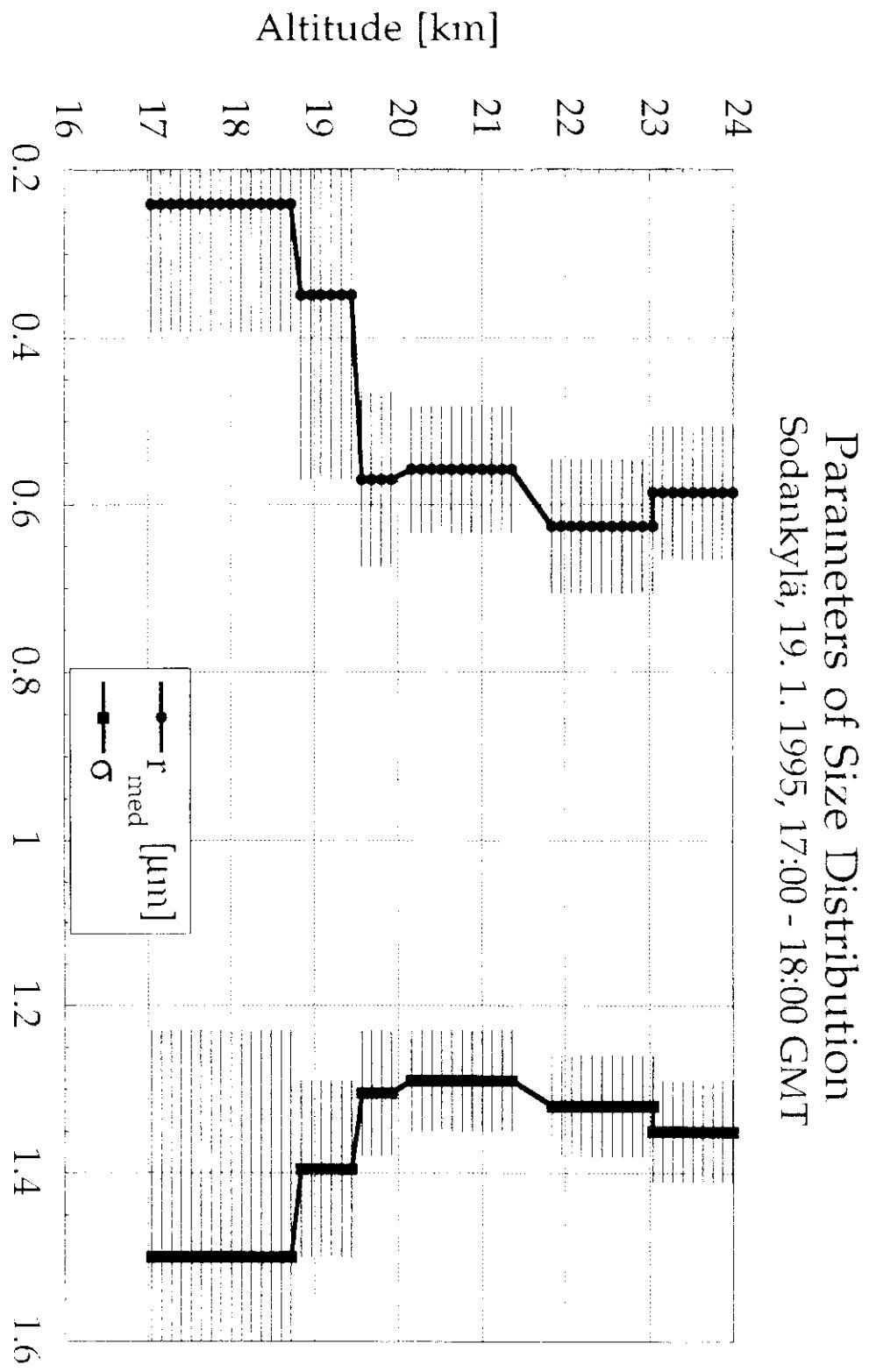
## Ti:Saphir-Lidar Signal am Maximum der Pinatubo Belastung



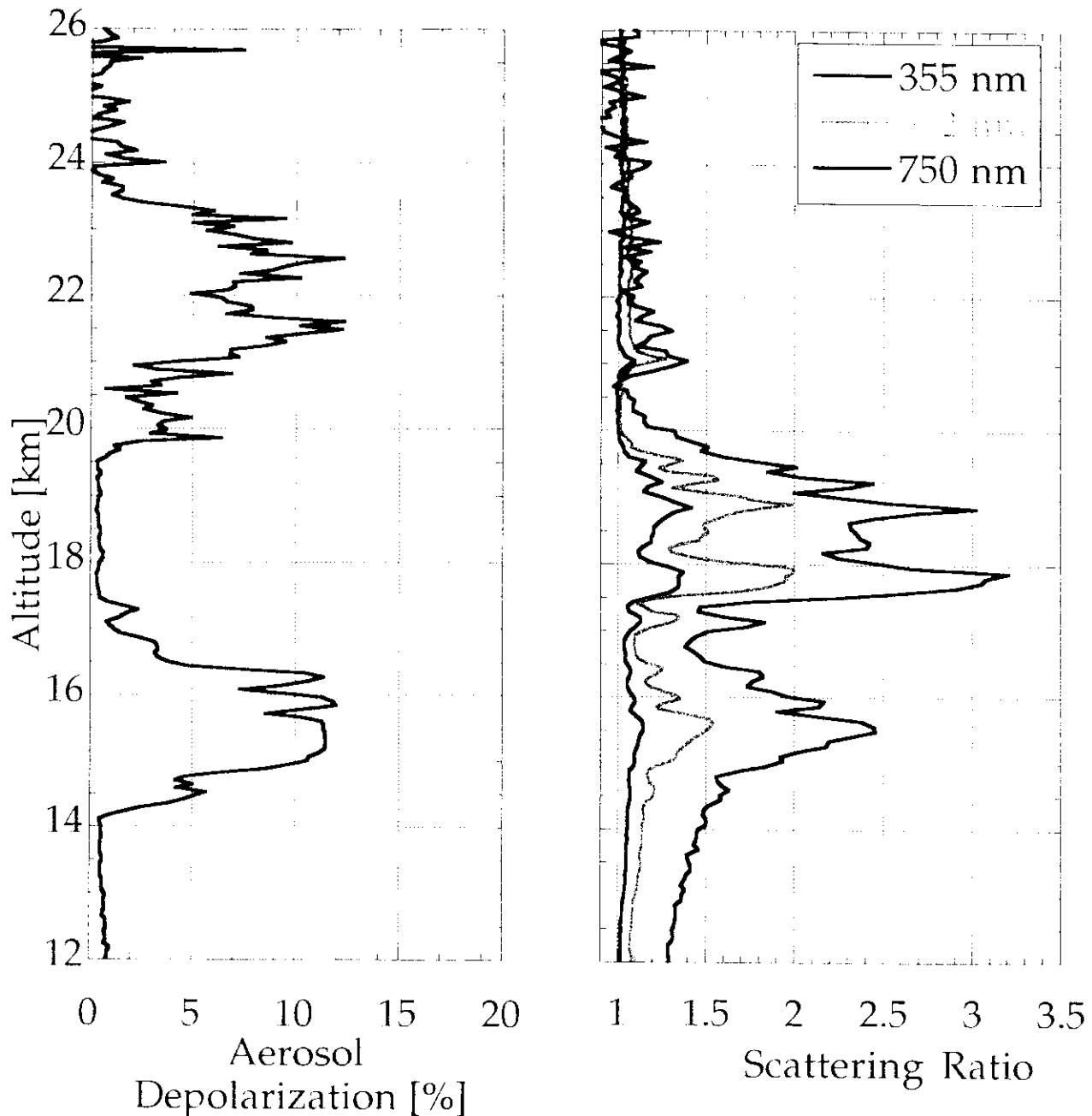
# Liquid PSC over Sodankylä



Weil STS so schön flüssig! Präzise Mic - Größenanalyse C. W.

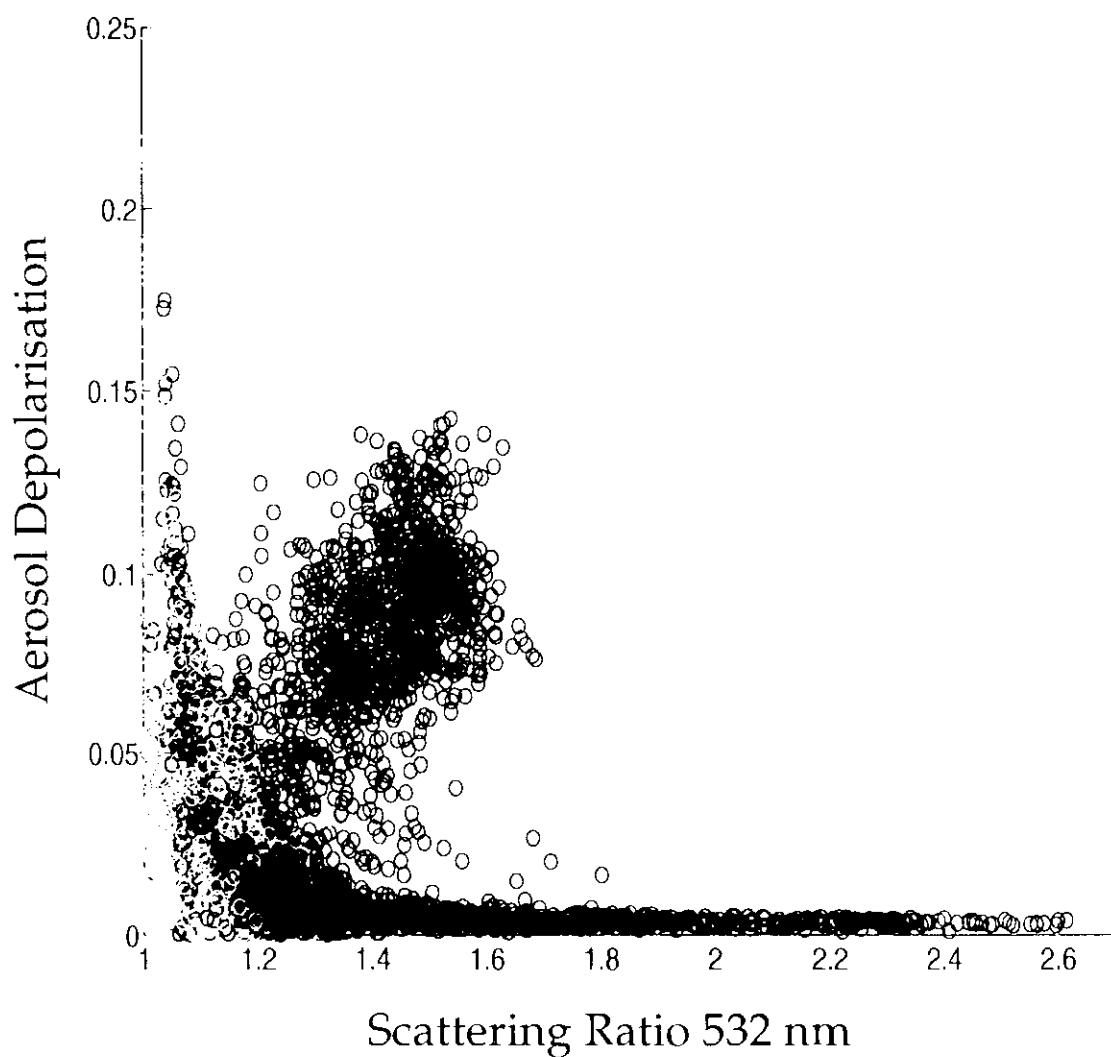


## Observation of different PSC-Types

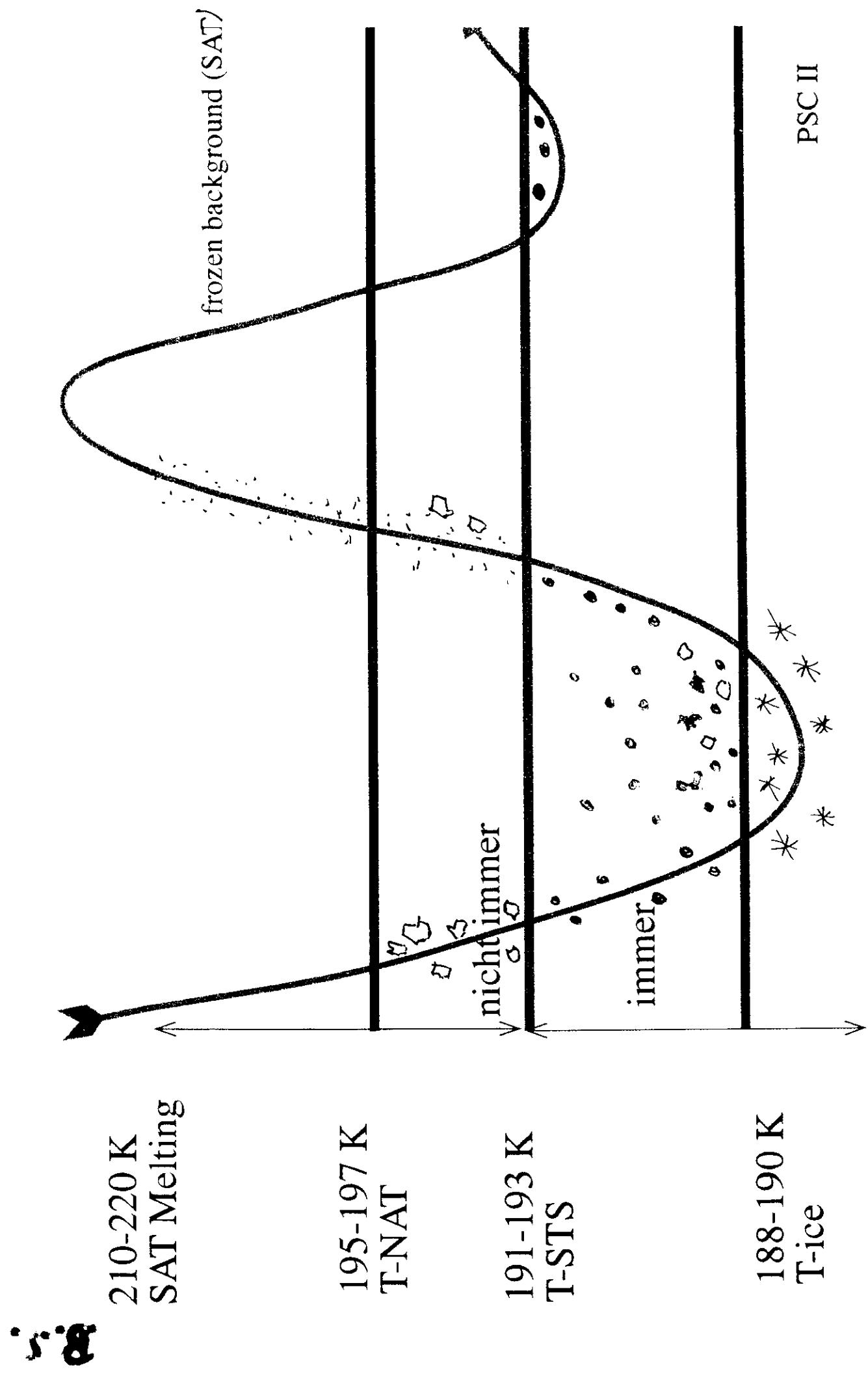


Sodankylä 12/01/1995 21:30-22:00 GMT

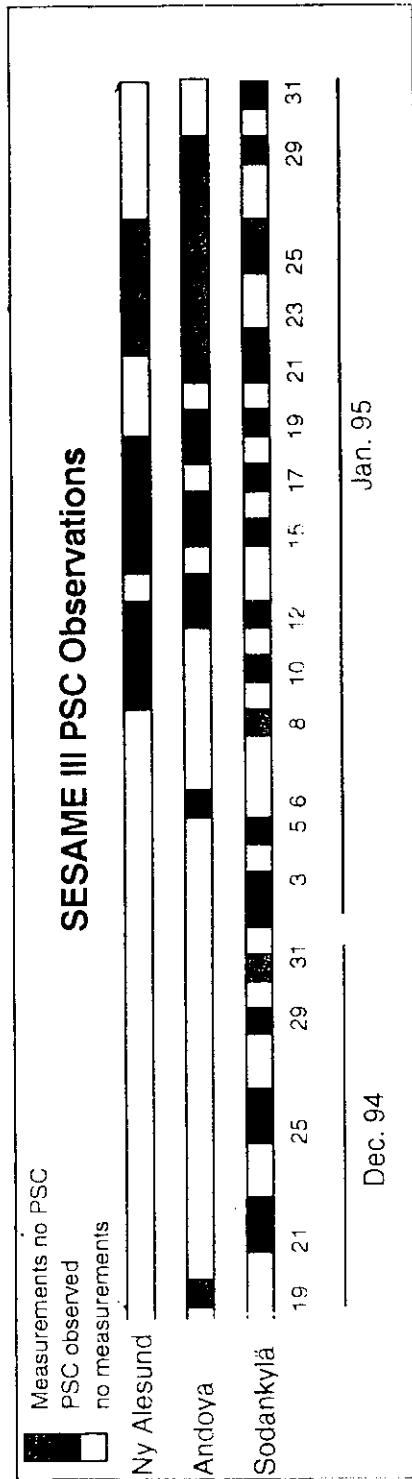
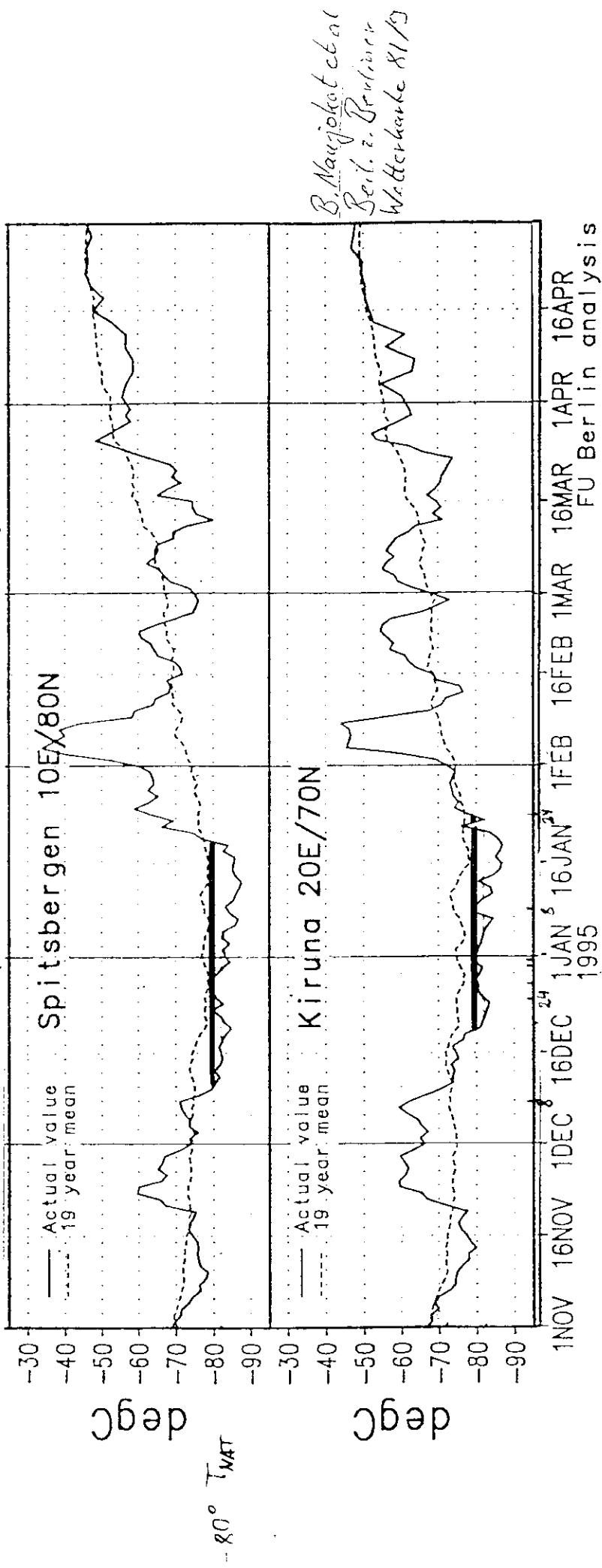
# Sodankylä 12/01/95



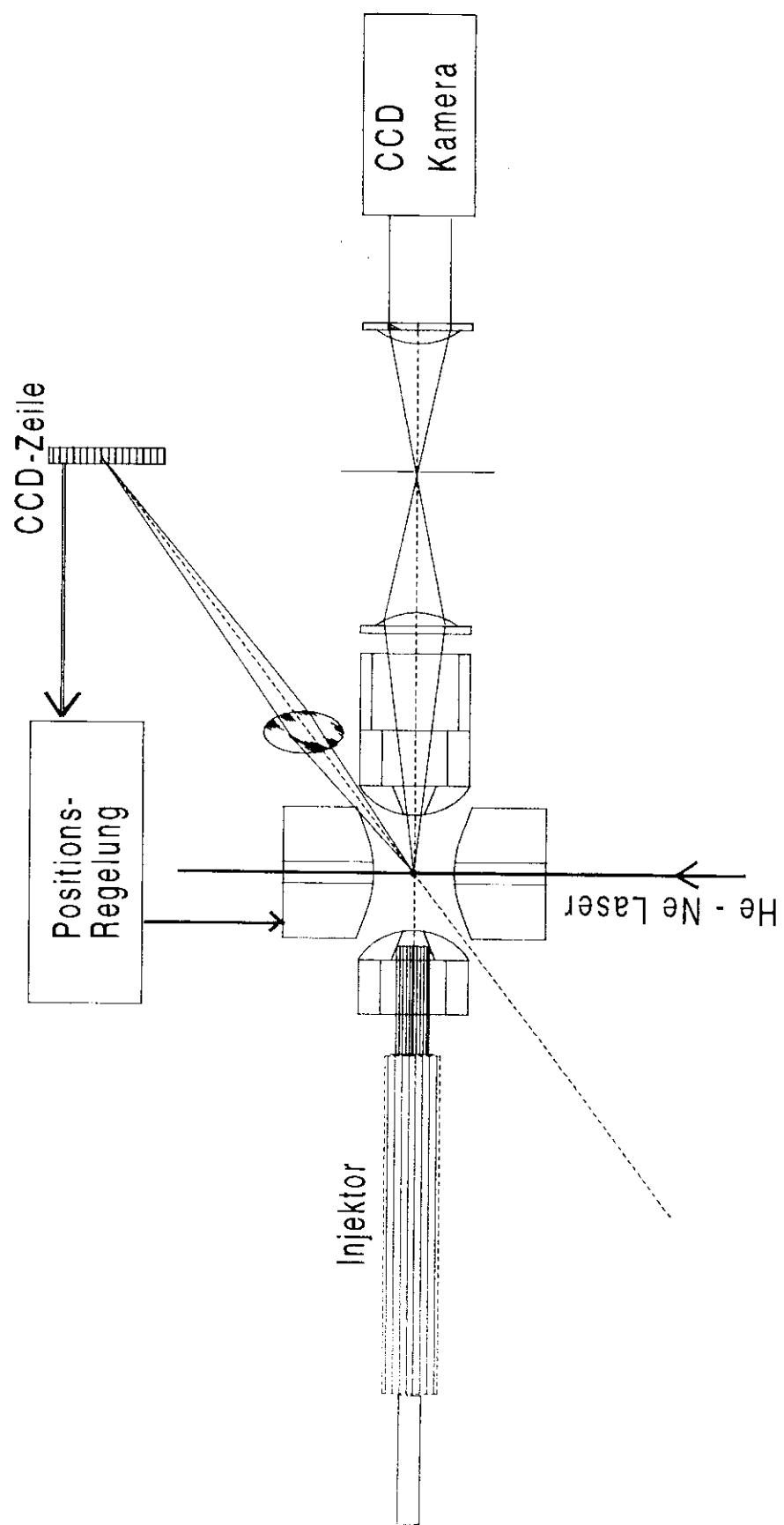
# Lidar Beobachtungen von vSUS (I-history)

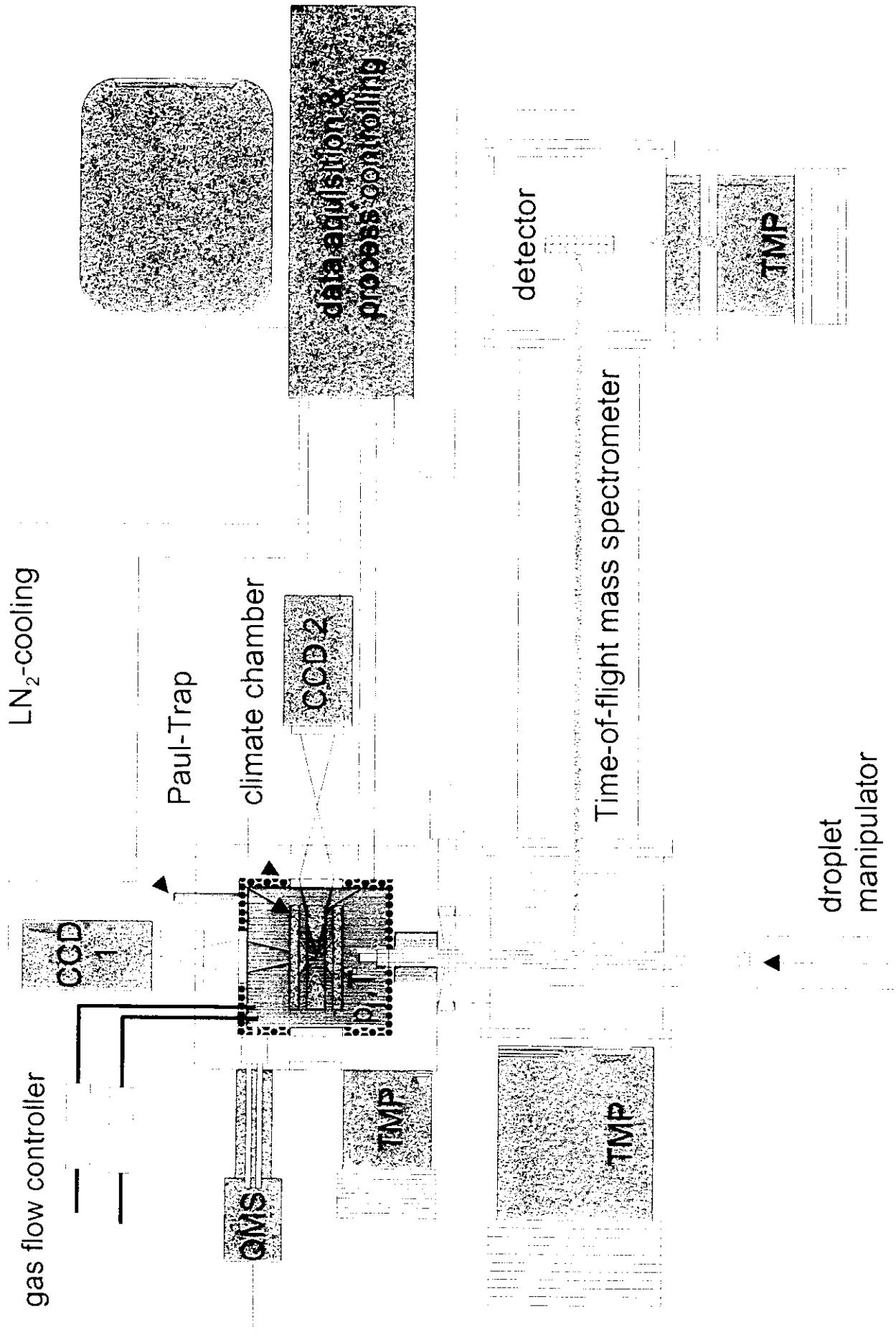


# 30hPa Temperatures 19C4/95

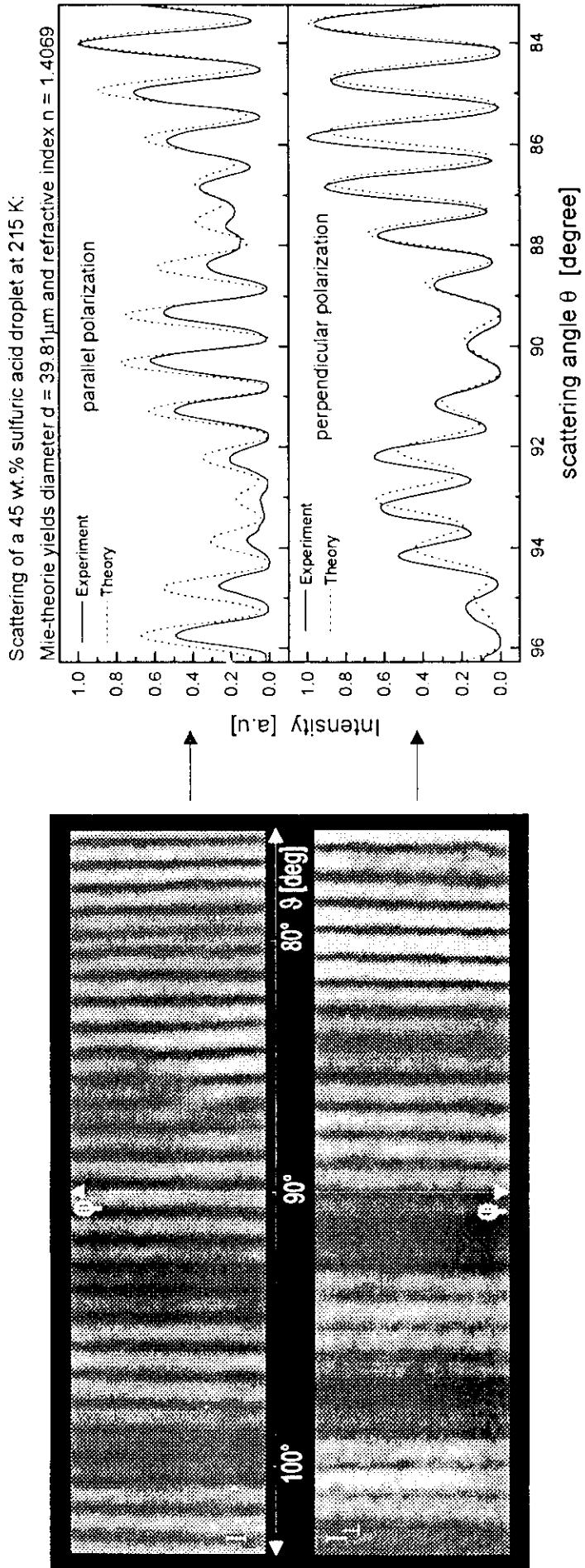








## Determination of diameter and index of refraction



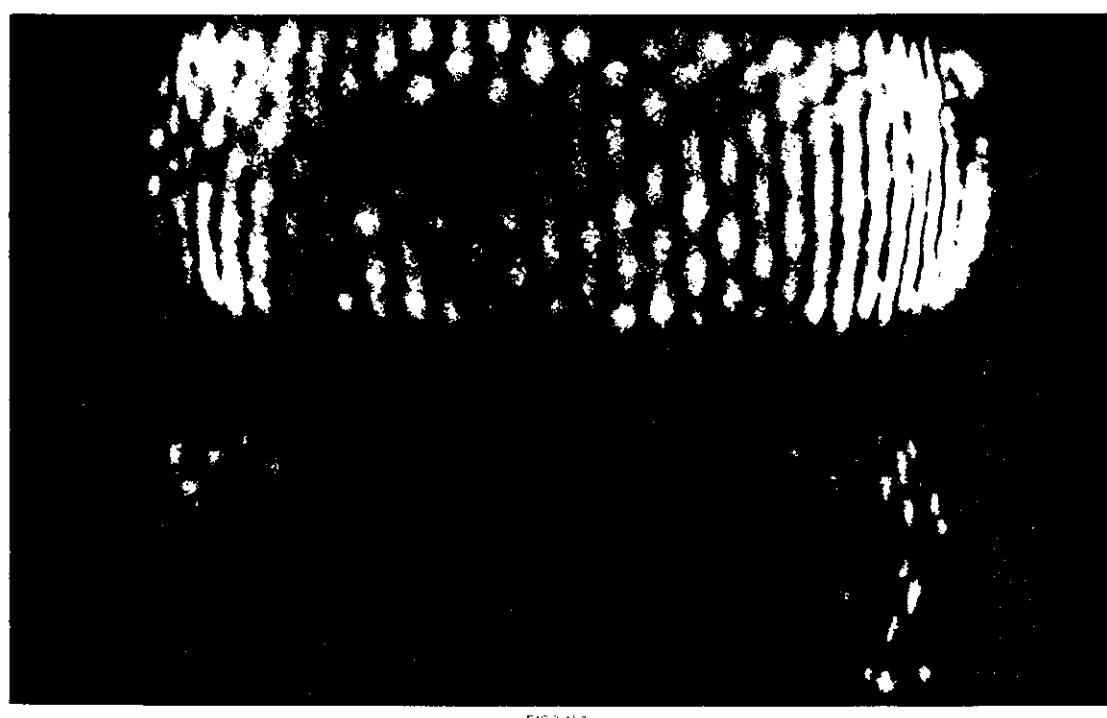
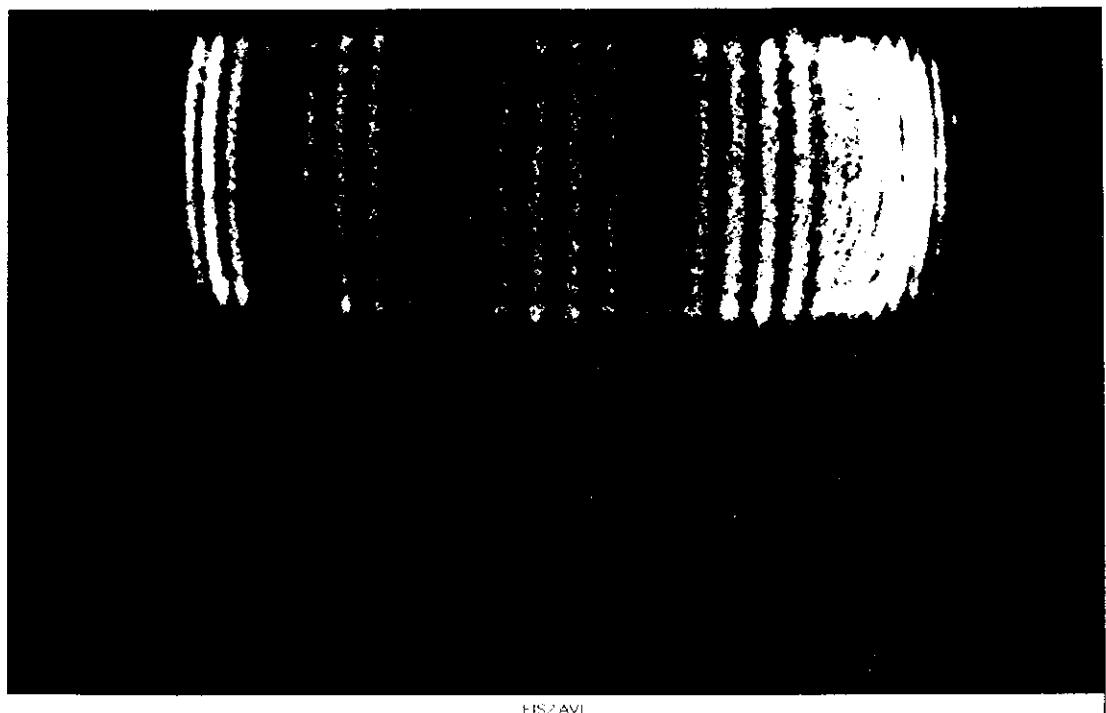
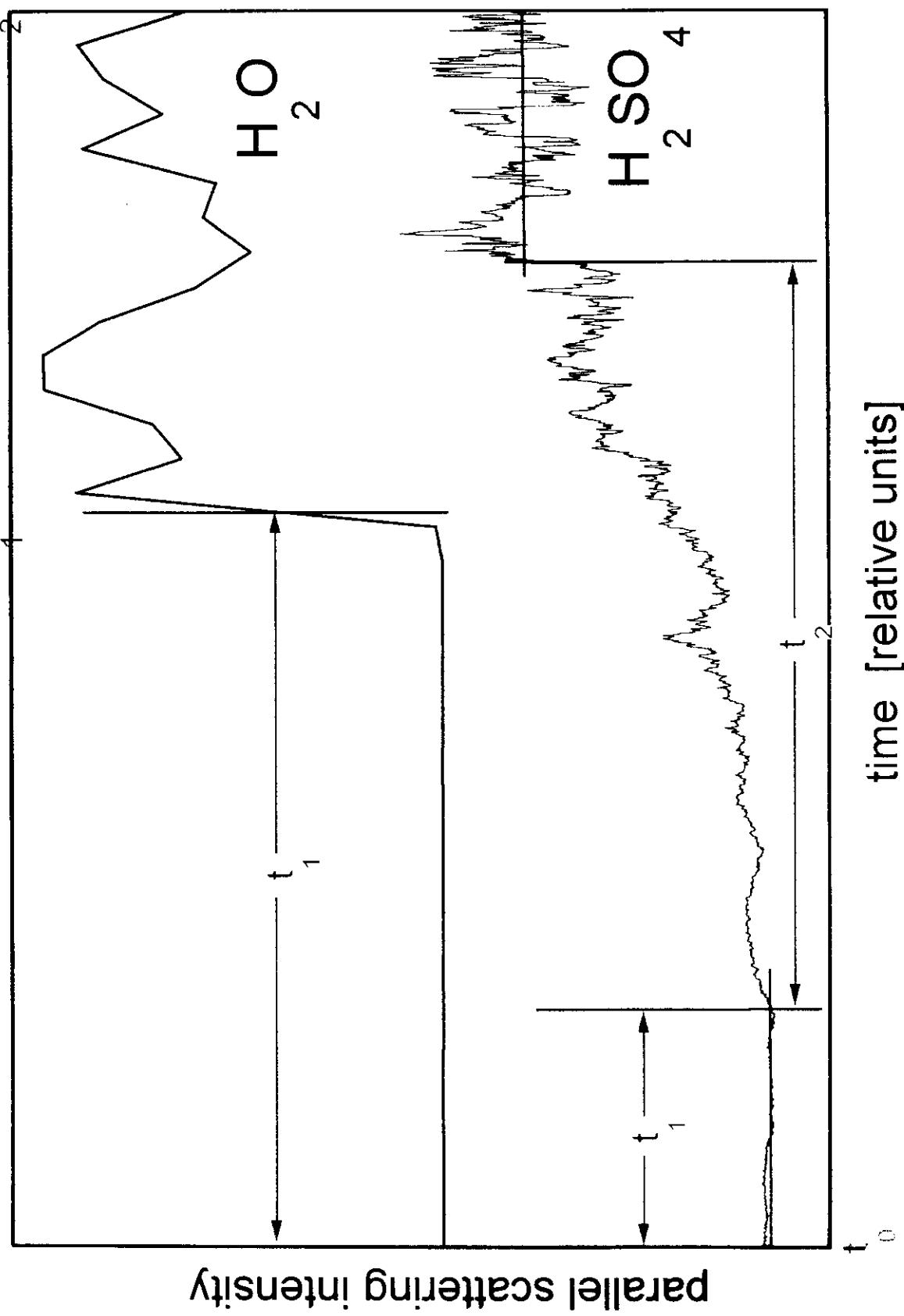
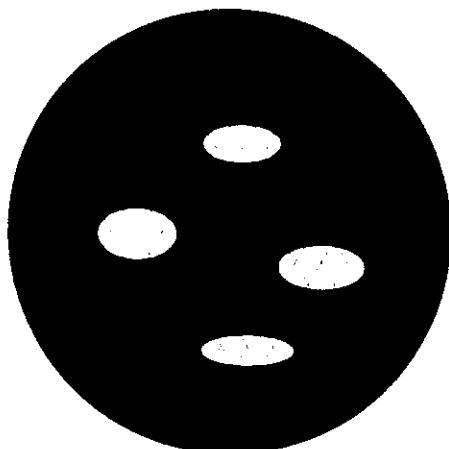


Abb. 7) Streuung eines p-polarisierten HeNe Lasers an einem Wasser (a,b) bzw. Eis (c,d)- Partikel.  
Die gestreute Strahlung ist nach p- (a,c) und s- (b,d) Polarisation getrennt.  
Dentlich ist die erhöhte Depolarisation des Eispartikels zu erkennen (d).

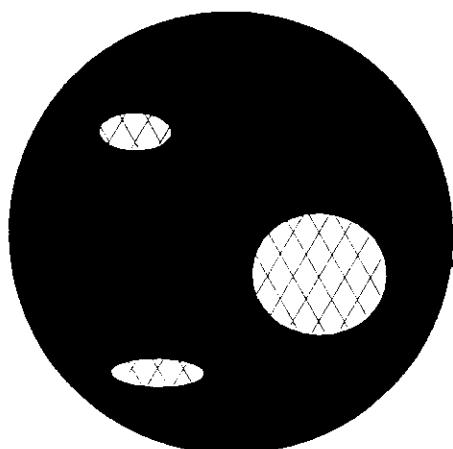
Determination of nucleation time  $t_1$  and crystallization time  $t_2$



# Homogeneous Nucleation



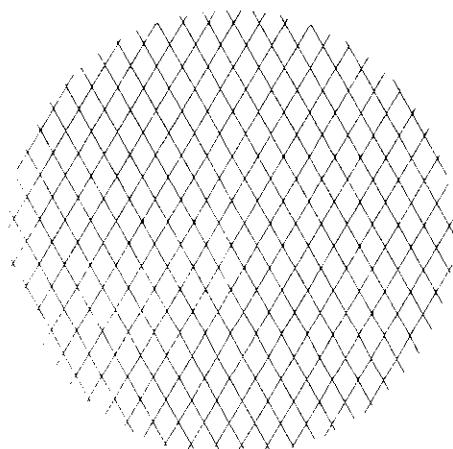
In an undercooled liquid  
are clustered regions



Statistical density-  
fluctuations create a germ  
of critical size

Germ of critical size

Germ formation energy

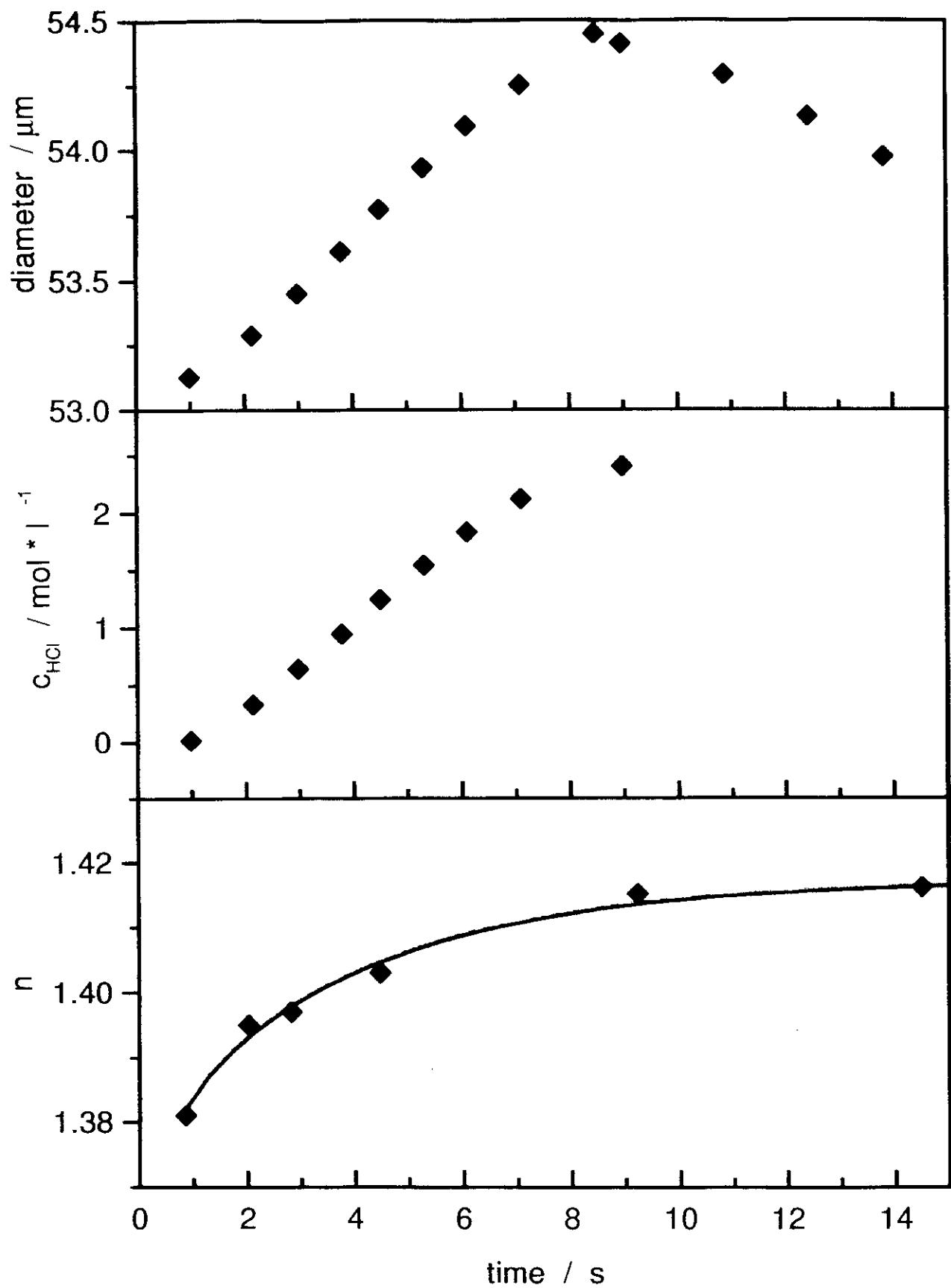


Further growing of the germ  
through diffusion and  
reorientation of molecules or  
clusters

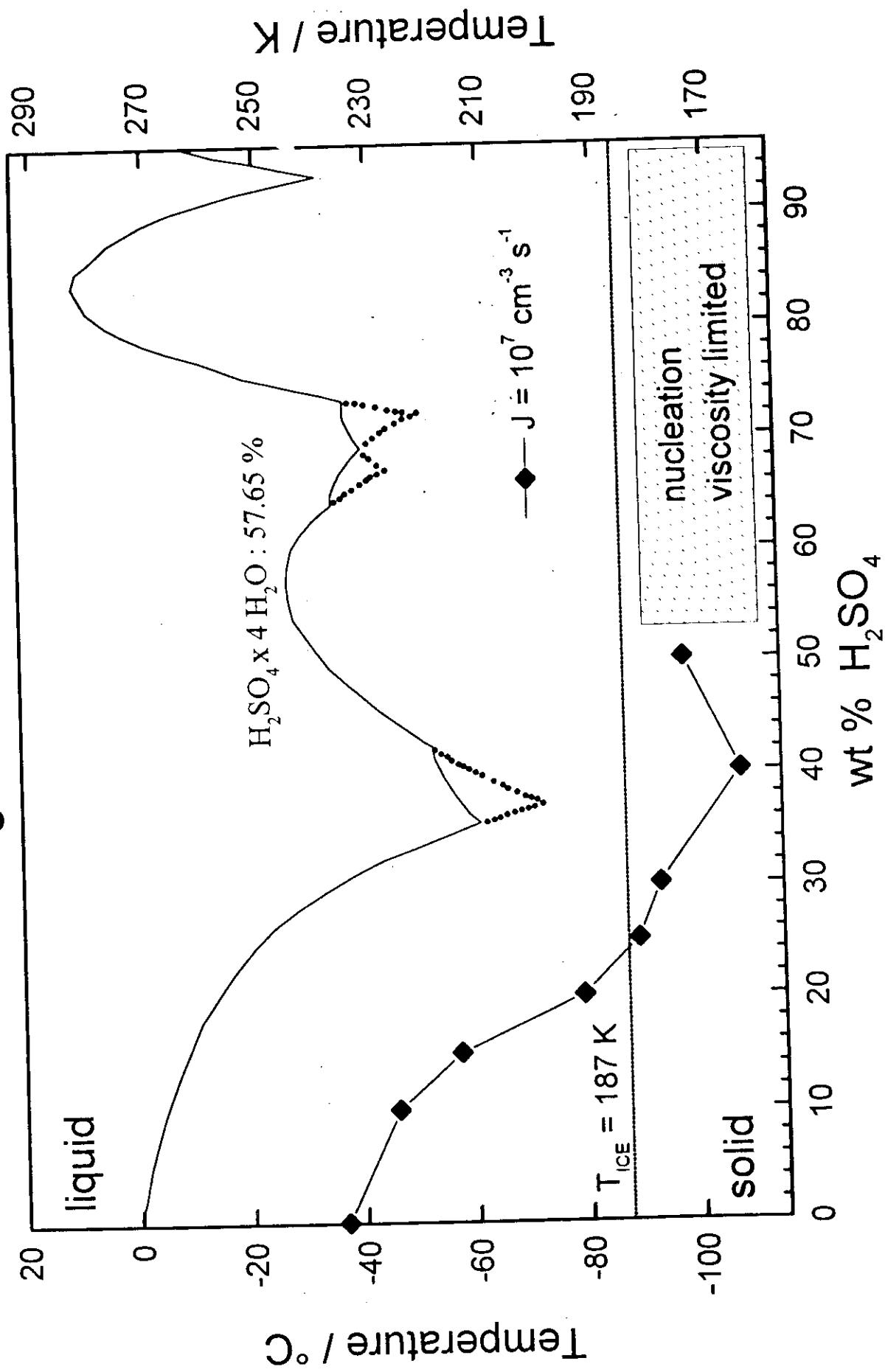
Activation energy

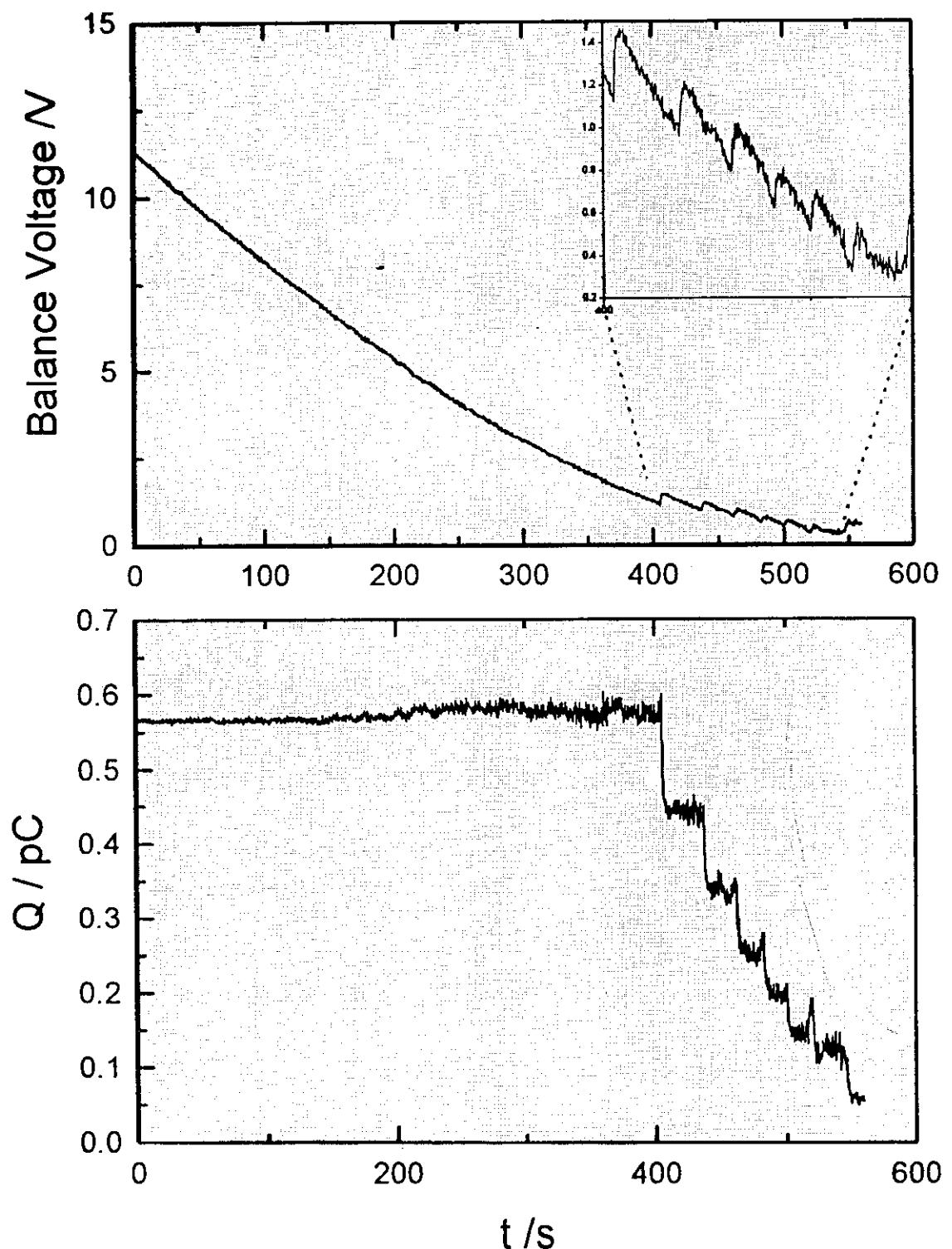
HCl - uptake of a 30%  $\text{H}_2\text{SO}_4$  droplet

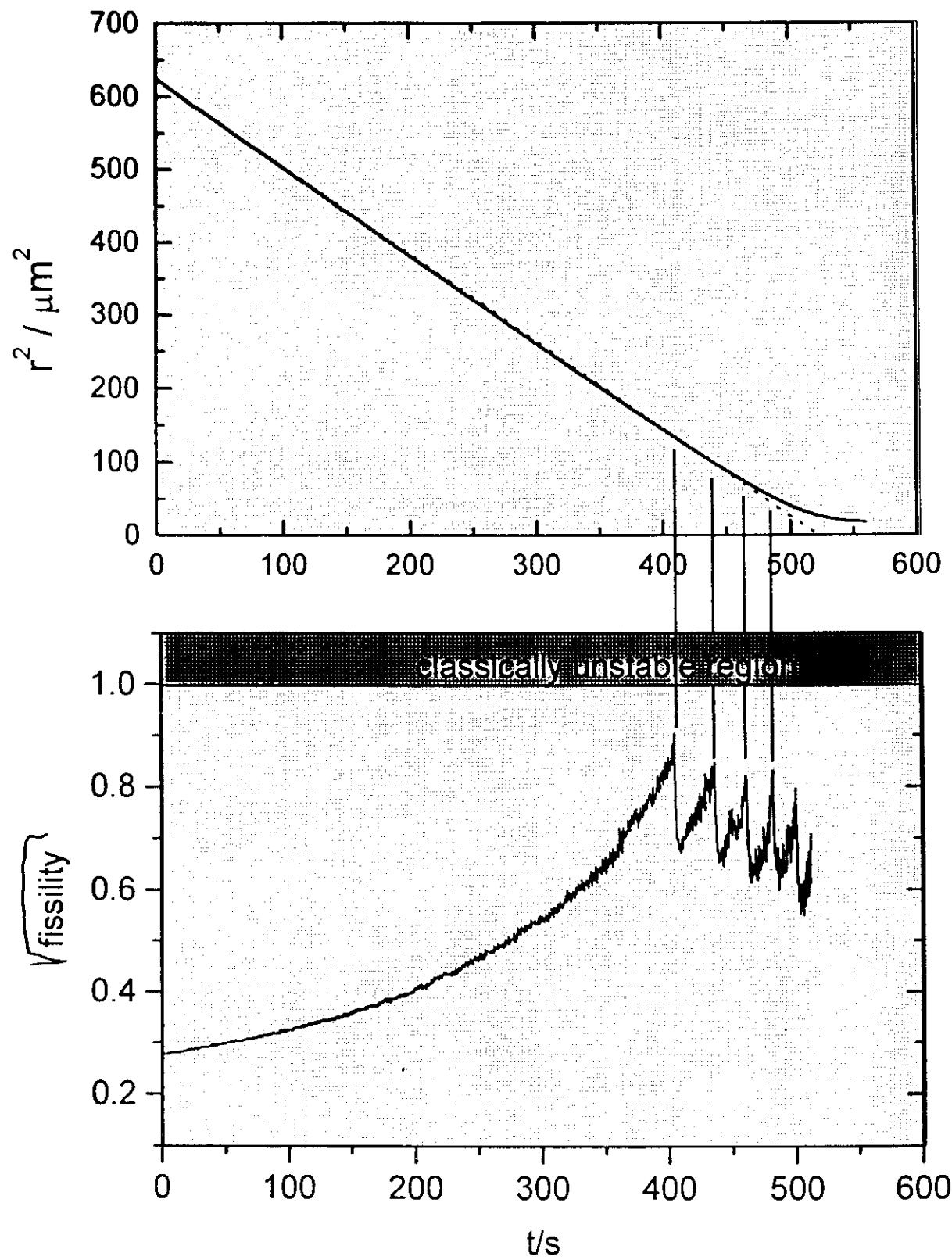
$T = -42^\circ\text{C}$ ,  $P_{\text{Total}} = 250 \text{ mbar}$ ,  $P_{\text{HCl}} = 5.9 \times 10^{-5} \text{ atm}$



## Phase diagram and nucleation rates







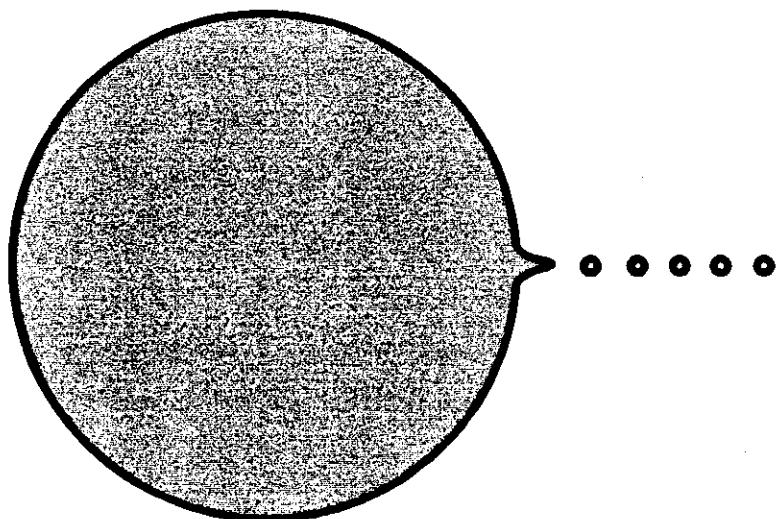
## Summary of the experimental results for the coulomb instability of highly charge droplets:

---

glycol droplets in the  $\mu\text{m}$  size range are getting unstable well below the critical raleigh parameter

in every single disruption, they loose about 25% of their charge but only about 1% of their mass

From momentum conservation, we conclude that a spray of at least ten small droplets is emitted preferentially in one direction



## Coulomb instability of Glycol droplets at room temperature

