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AUTUMN COLLEGE

ON

THE TROPOSPHERE, STRATOSPHERE AND MESOSPHERE

10 September - 19 October 1984

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# MEASURING TECHNIQUES AND MEASUREMENTS :

# GROUND-BASED, LIDAR AND ROCKETS

(Additional diagrams and notes on radar measurements)

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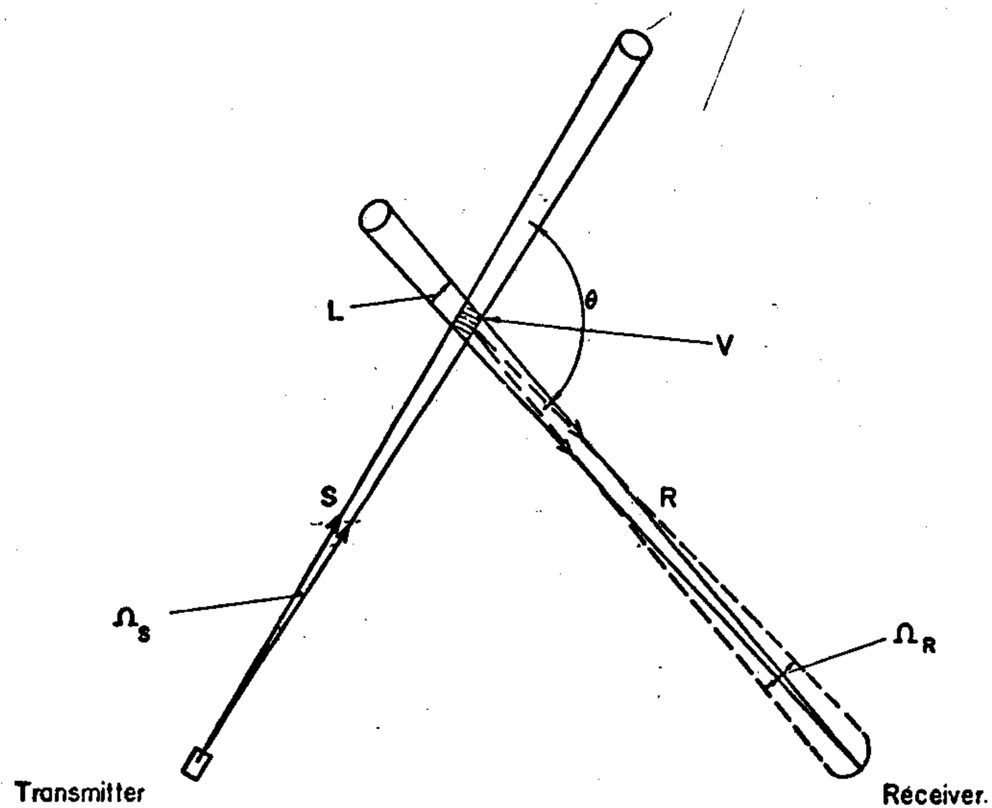



Fig.1 Geometry of Bistatic Radar System



$$C = N_t \frac{1}{4\pi S^2} \cdot \frac{4\pi}{\Omega_s} \cdot \exp\left(-\int_0^S \gamma_s(S)\, dS\right)\left(\sigma_\theta\, \Omega_R\right) nV \cdot \exp\left(-\int_0^R \gamma_R(R)\, dR\right)\eta$$

$$= \frac{N_t \exp\left(-\int_0^S \gamma_s(S)\, dS\right) \cdot \exp\left(-\int_0^R \gamma_R(R)\, dR\right) \cdot \sigma_\theta\, L\, A\, n\, \eta}{R^2}$$

Since $V = S^2 \Omega_s L$ and $\Omega_R = \frac{A}{R^2}$

Lidar equation for vertical incidence..

$$C = N_t \frac{T^2 \sum_i (\sigma_i n_i) A S h \eta}{h^2}$$



## Rayleigh Scattering

Size of particle in relation to wavelength

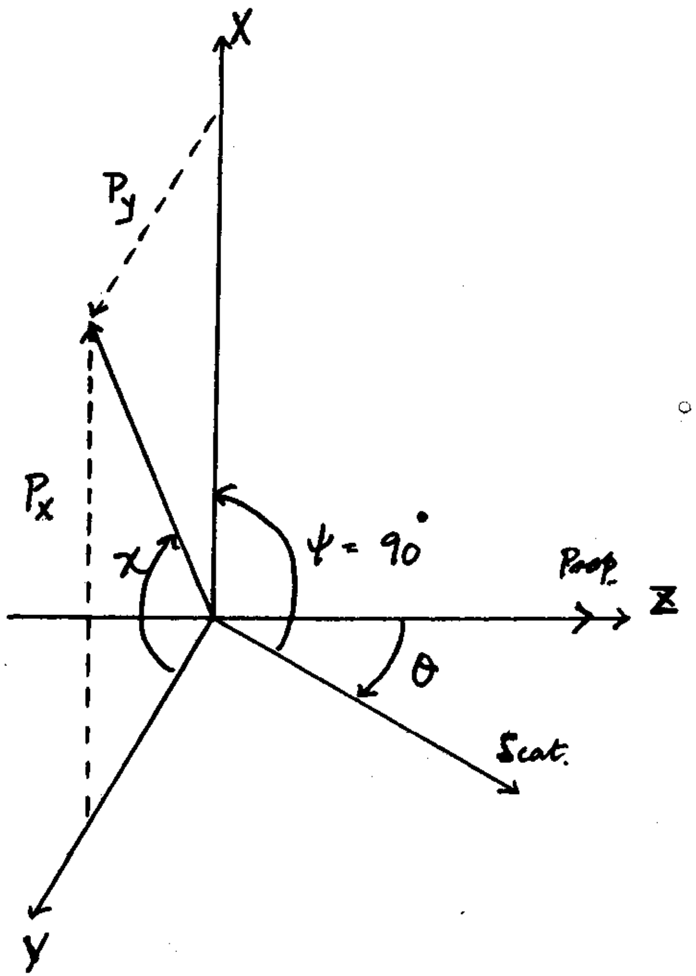
$$a n_1 << \lambda/2\pi$$

a - radius , $n_i$ refractive index

Scattering particles are non conductors
& do not contain free electrons

Dielectric constant of particle &
medium differ by small amount

Particles scatter independently




Intensity of scattered radiation at distance $r$ for incident radiation of unit intensity

$$I_{vert}(\chi) = \frac{16\pi^4 a^6}{r^2\lambda^4}\left(\frac{n^2-1}{n^2+2}\right)^2 \sin^2\chi$$

$$I_{horiz}(\chi) = \frac{16\pi^4 a^6}{r^2\lambda^4}\left(\frac{n^2-1}{n^2+2}\right)^2 \cos^2\chi \cos^2\theta$$

where $n = \dfrac{n_1}{n_2} = \dfrac{\text{RI scatterer}}{\text{RI medium}}$

No phase difference & azimuth of scattered radiation $(\chi')$

$$\left[\frac{I_{vert}(\chi)}{I_{horiz}(\chi)}\right]^{\frac{1}{2}} = \tan\chi' = \frac{\tan\chi}{\cos\theta}$$

∴ Azimuth angle rotated for all angles of observation, except for forward & backward scattering

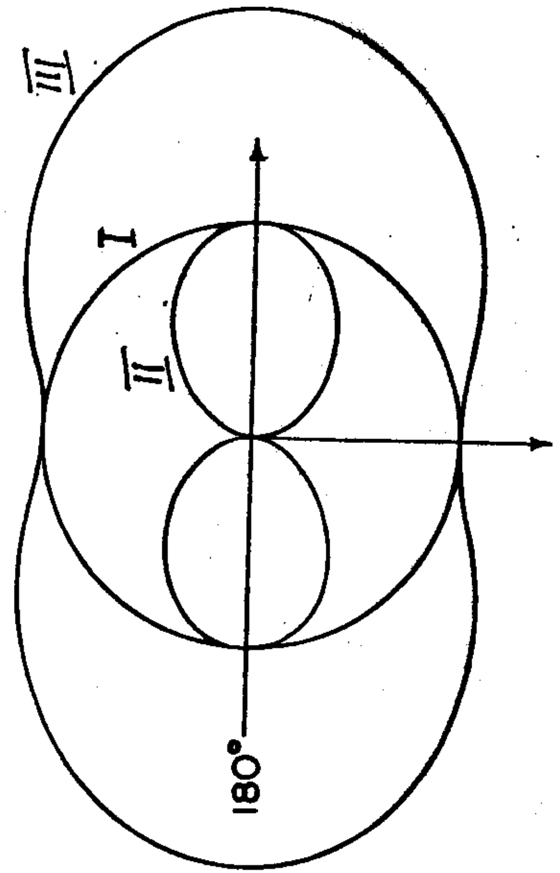
For unpolarised incident wave scattered radiation can be resolved into two components polarised $\perp$ and $\parallel$ to scattering plane

Intensity

$$= \frac{I_1 + I_2}{2} = \frac{8\pi^4 a^6}{r^2 \lambda^4} \left(\frac{n^2-1}{n^2+2}\right)^2 (1 + \cos^2\theta)$$

$\perp$ component

$\parallel$ component




Radiation pattern of scattered radiation for incident beams of equal intensity polarised vertically (I), polarised horizontally (II), and unpolarised (III).

Rayleigh Scattering cross-section

$$= \frac{128\pi^5 a^6}{3\lambda^4}\left(\frac{n^2-1}{n^2+2}\right)^2$$

Differential backscatter function (fraction of light backscattered per unit solid angle

$$= \frac{16\pi^4 a^6}{\lambda^4}\left(\frac{n^2-1}{n^2+2}\right)^2$$

Differential Rayleigh backscatter cross section

$$\sigma_i = 5.45\left(\frac{\lambda\,\mu m}{0.55}\right)^{-4} \times 10^{-28}$$

$cm^2\, ster^{-1}$

Also

Attenuation by scattering :

$$\frac{\underline{\text{Backscatter coefficient}}}{\text{Extinction or Attenuation coefficient}} = \frac{1.5}{4\pi}$$



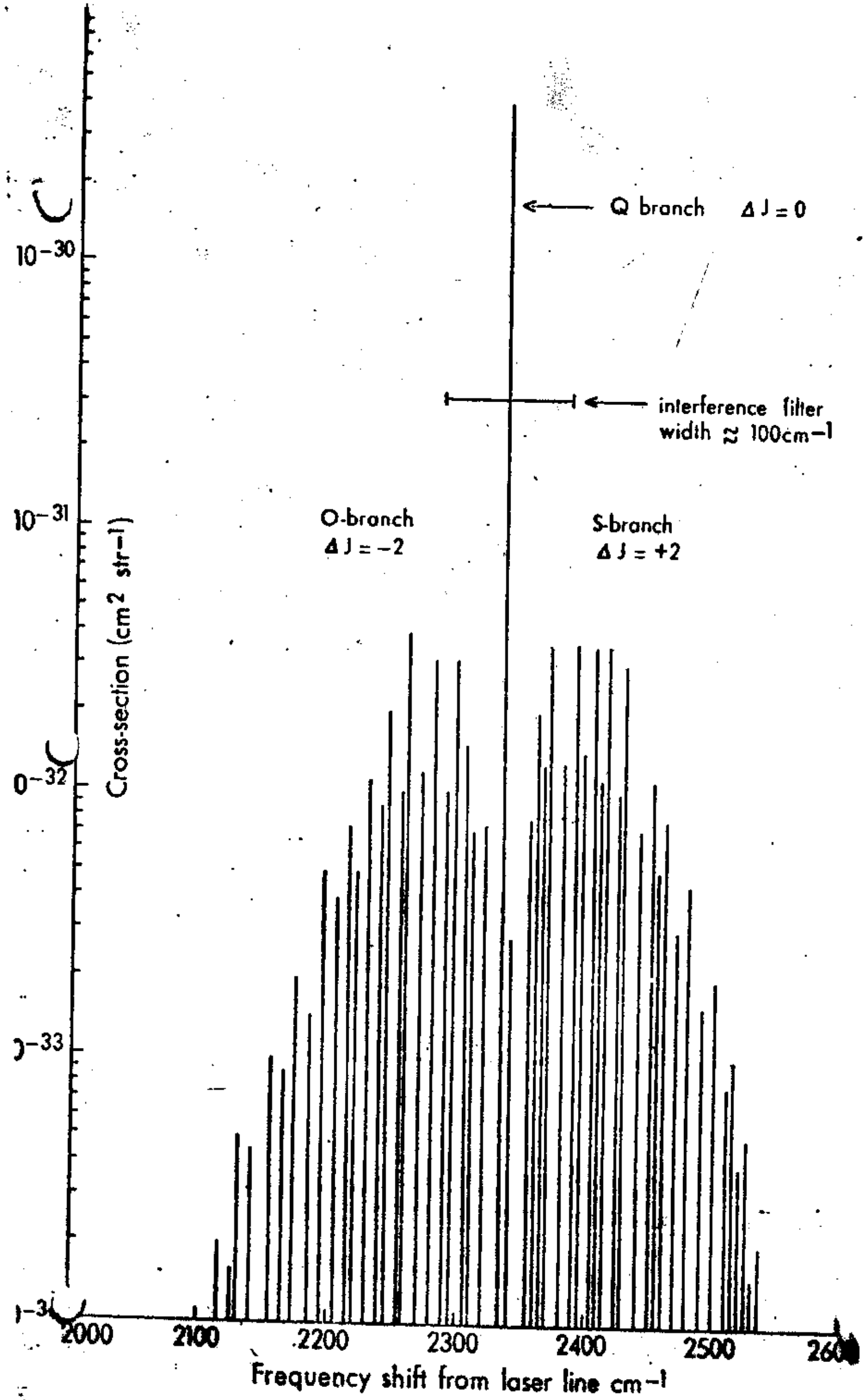
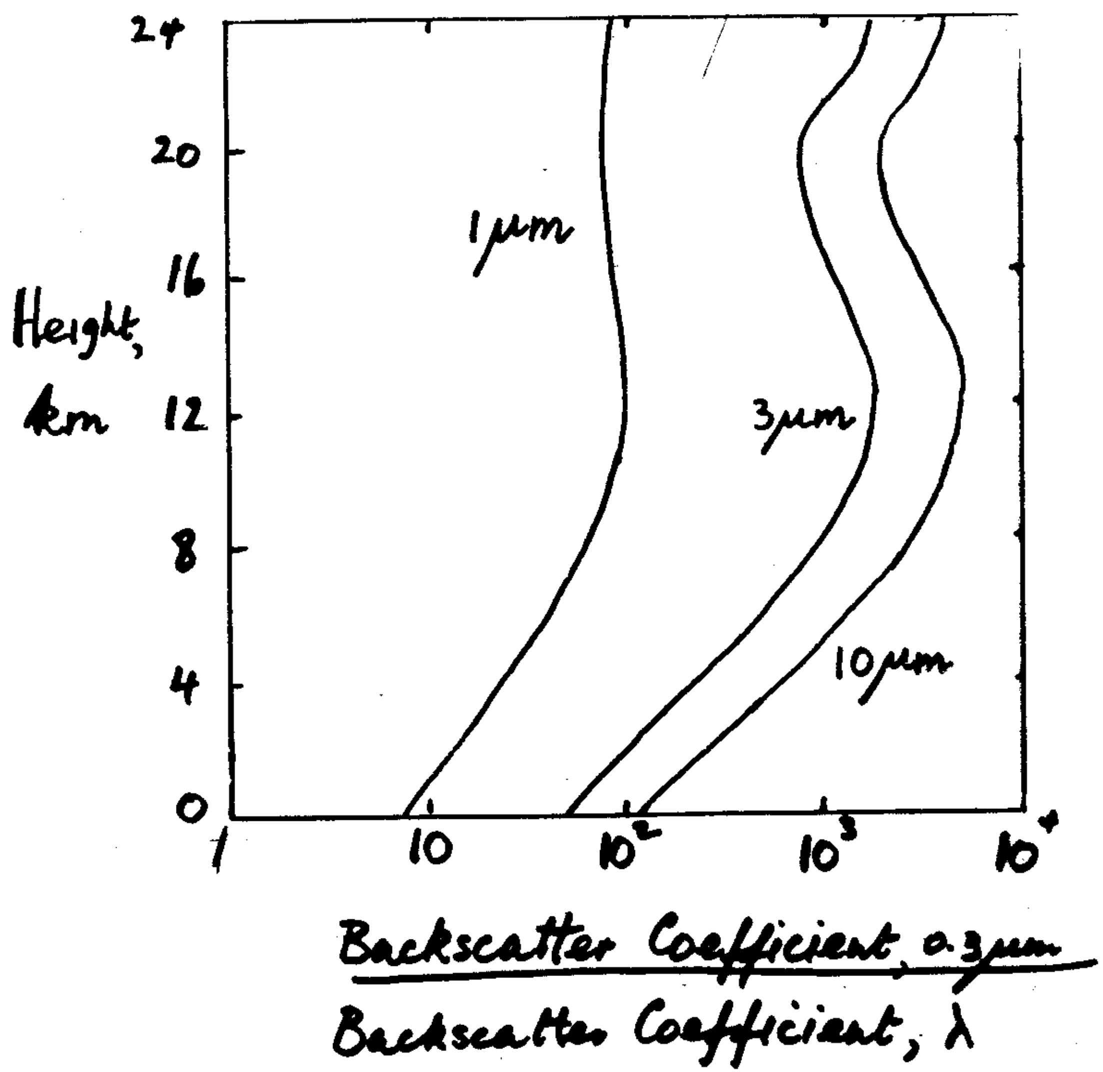


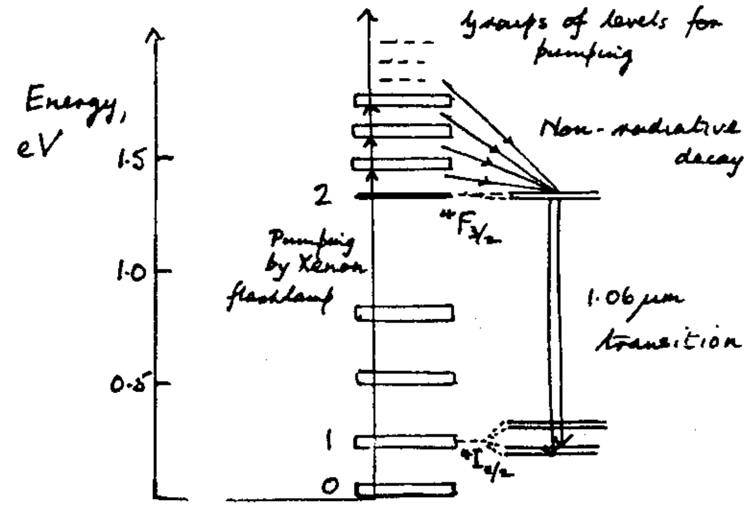

Figure 2.2 The vibration/rotation Raman spectrum of $N_2$



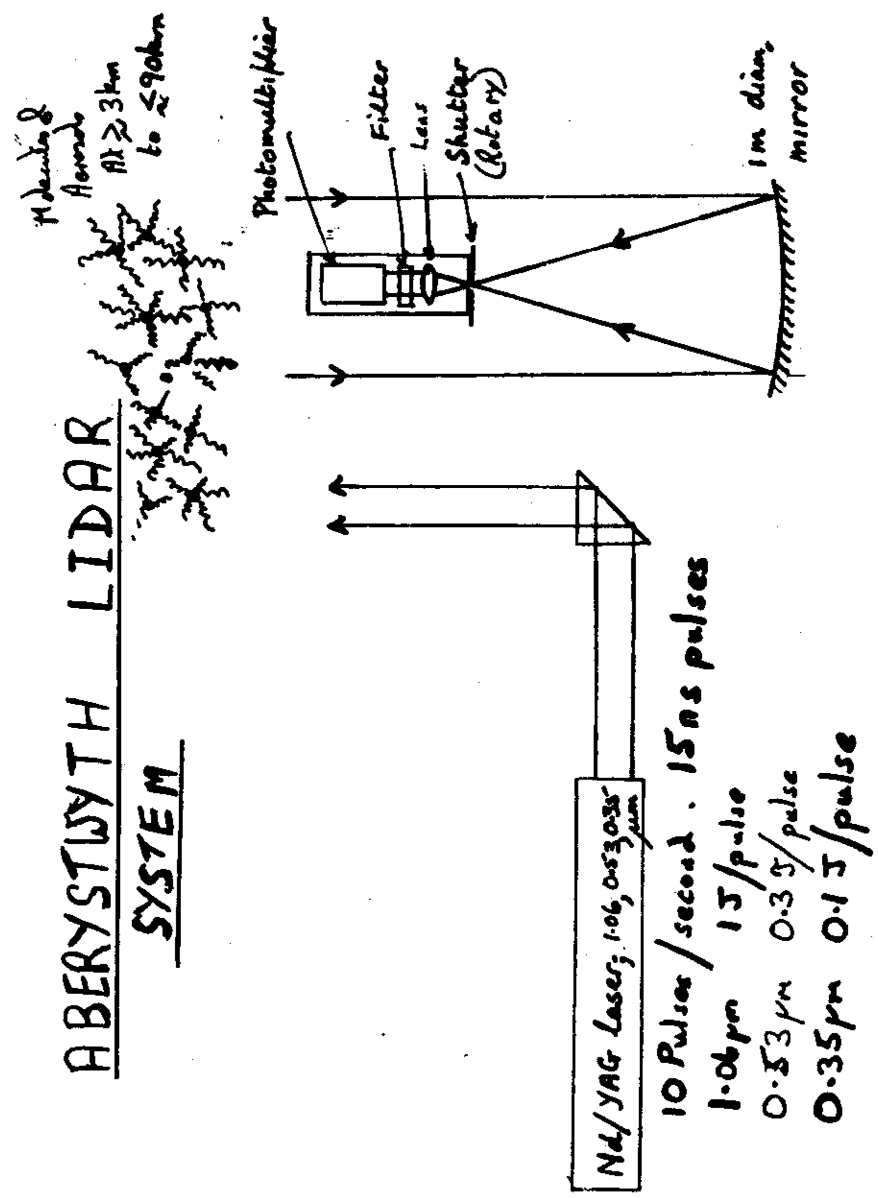

## Neodymium Yag laser

$Nd^{3+}$ present as impurity in Yttrium Aluminium Garnet ($Y_3Al_5O_{12}$)

The electrostatic field of surrounding Yag ions – the crystal field – interacts with energy levels of $Nd^{3+}$ ions – ground & first excited state energy levels are split into groups of levels

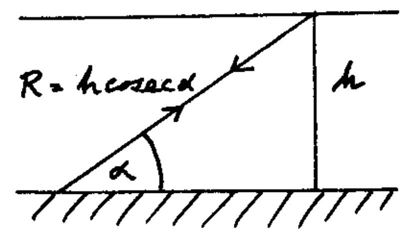


# ABERYSTWYTH LIDAR SYSTEM






In case of backscatter at elevation angle $\alpha$,




$$\exp\left(-\int_0^s \gamma_s(s)\,ds\right) = \exp\left(-\int_0^R \gamma_R(R)\,dR\right)$$

$$= \exp\left(-\int_0^h \gamma(h)\,\mathrm{cosec}\,\alpha\,dh\right)$$

$$= T^{\mathrm{cosec}\,\alpha}$$

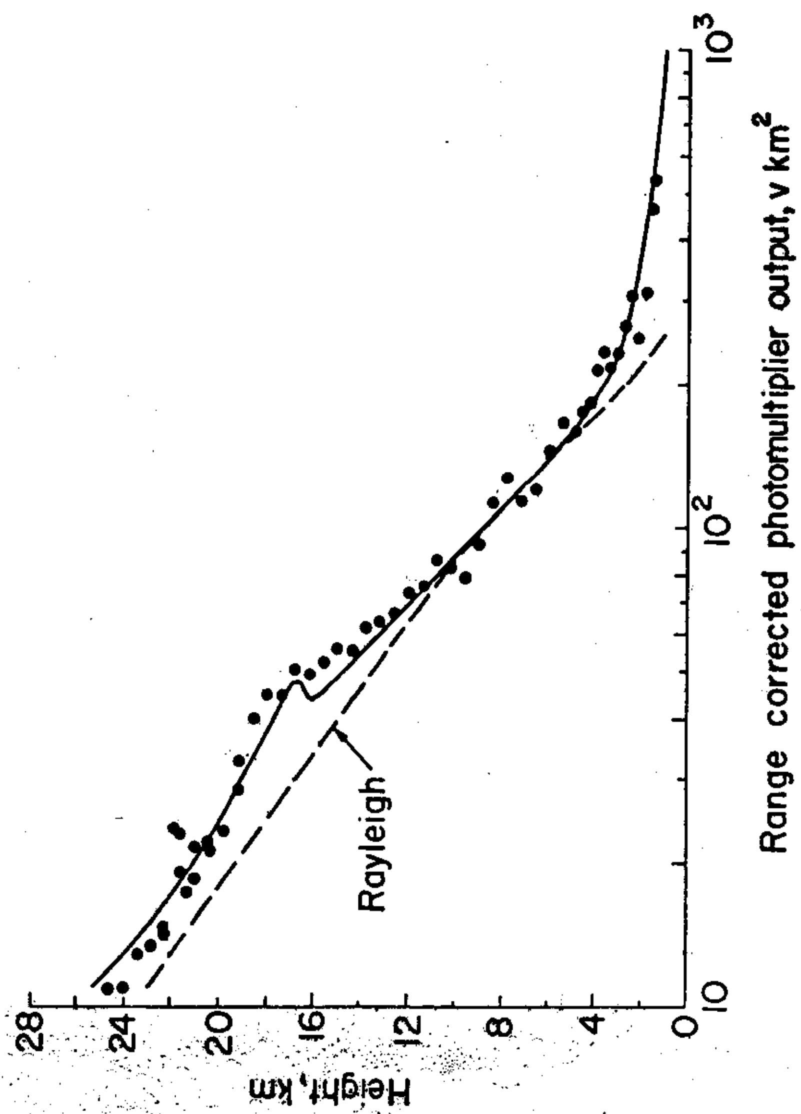
if $T$ represents transmission at vertical incidence.

Radar equation then takes form

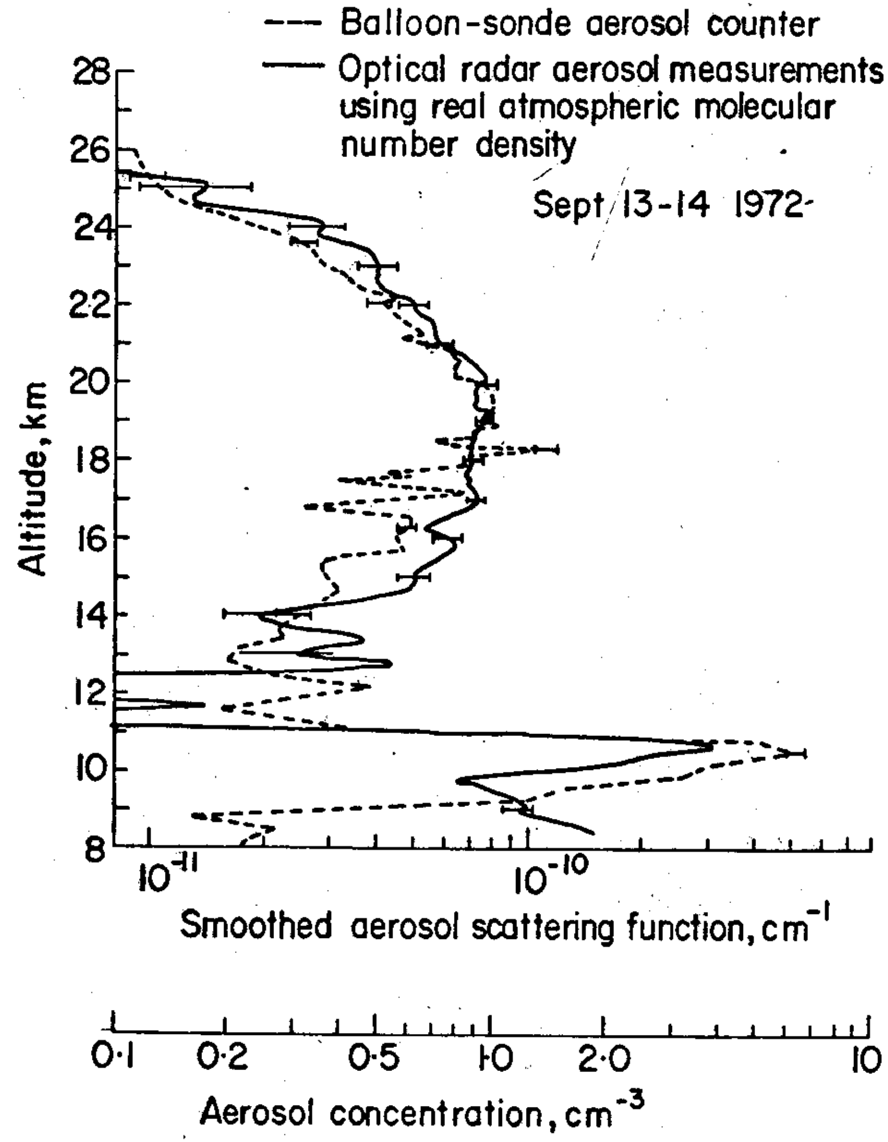
$$C = \frac{N_t\, T^{2\,\mathrm{cosec}\,\alpha}\, A\eta\, \Sigma_i(\sigma_i n_i)\, \delta R}{h^2\,\mathrm{cosec}^2\alpha}$$

where $\sigma_i$ refers to backscatter.

$\therefore \log C = 2\,\mathrm{cosec}\,\alpha . \log T - 2 \log \mathrm{cosec}\,\alpha$ + term independent;


Range corrected photomultiplier output, v km$^2$
Height, km
Rayleigh

15

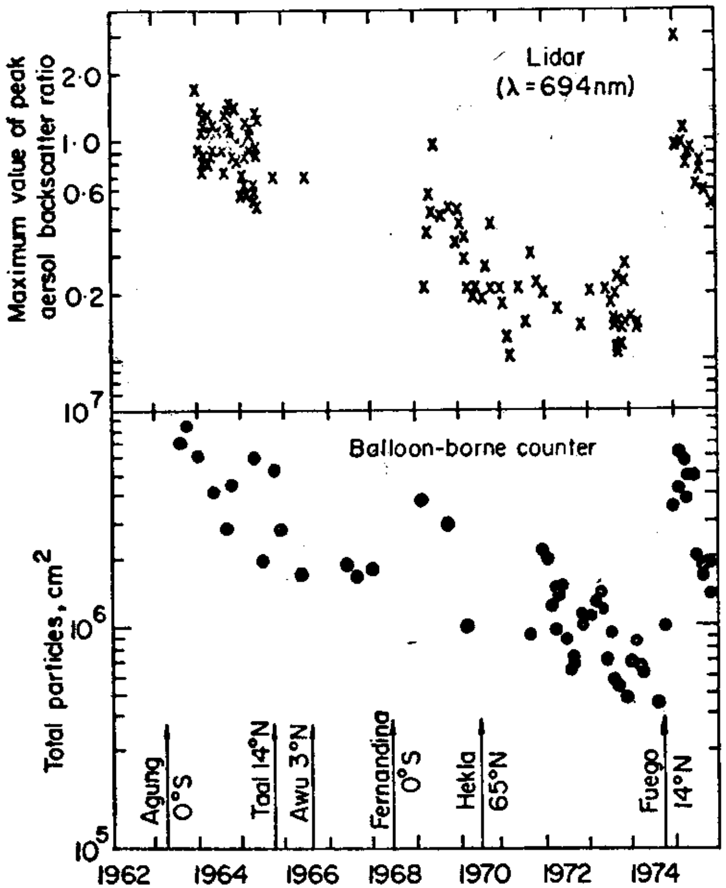

Balloon-sonde aerosol counter
Optical radar aerosol measurements using real atmospheric molecular number density
Sept 13-14 1972
Altitude, km
Smoothed aerosol scattering function, cm$^{-1}$
Aerosol concentration, cm$^{-3$}

16

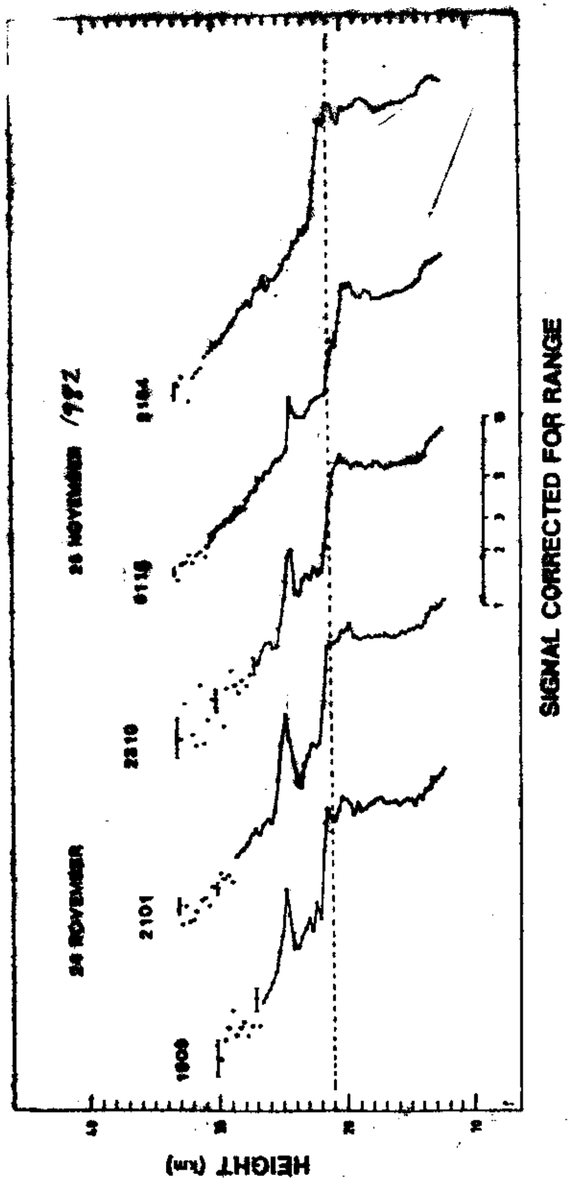
$$R = \frac{\Sigma_i(\sigma_i \; n_i)}{\sigma_m \; n_m}$$

$$= 1 + \frac{\Sigma(\sigma_a \; n_a)}{\sigma_m \; n_m}$$

*R-1 gives aerosol backscatter ratio*

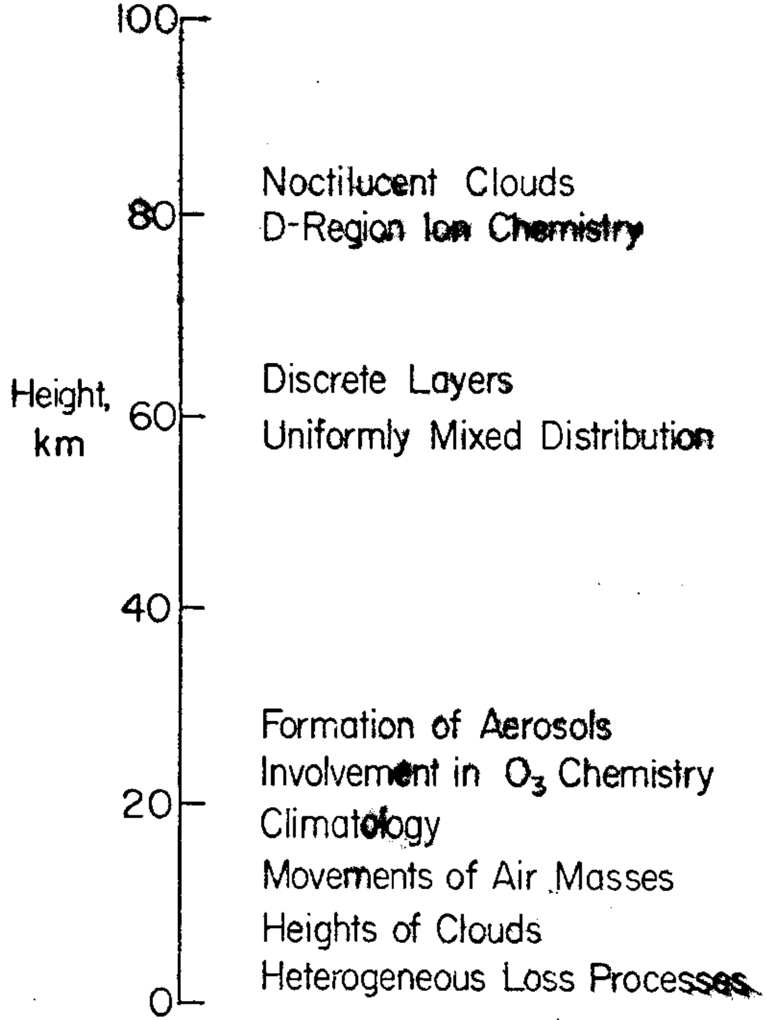


Aberystwyth






## Scientific Interest in Atmospheric Aerosols



## Measurement of ozone

This depends on strong absorption by ozone on ultra-violet radiations, particularly near peak of layer near 20 km.

For absorption or scattering, attenuation at vertical incidence between heights $h_1$ & $h_2$

$$= \exp\left(-\sigma(\lambda)\int_{h_1}^{h_2}[X].\,dh\right)$$

where [X] represents concentration at height h of absorbing or scattering constituent and $\sigma(\lambda)$ the appropriate cross-section at the wavelength concerned.

We have seen previously that the cross-section for attenuation by Rayleigh scattering of wavelength $\lambda$, in nm, is given by

$$5.45\left(\frac{\lambda}{550}\right)^{-4} \times \frac{4\pi}{1.5} \times 10^{-28}\ \text{cm}^2$$

$$= 4.62 \times 10^{-26}\ \text{cm}^2 \quad \text{for } \lambda = 300\,\text{nm}$$

Total molecular density near 20 km $= 2 \times 10^{18}\ \text{cm}^{-3}$

Attenuation coefficient $= 9.24 \times 10^{-8}\ \text{cm}^{-1}$



For ozone, peak concentration $\simeq 5.10^{12}\ \text{cm}^{-3}$

Also for 300 nm, ozone absorption cross-section

$$= 3.10^{-23}\ \text{m}^2 = 3.10^{-19}\ \text{cm}^2$$

Attenuation coefficient for absorption near peak of layer

$$= 5.10^{12} \times 3.10^{-19}\ \text{cm}^{-1}$$

$$= 1.5 \times 10^{-6}\ \text{cm}^{-1}$$

i.e. More than 16 times greater than that imposed by Rayleigh scattering.

$$T(\lambda, h) = \exp\left(-\sigma_{O_3}(\lambda) \int_0^h [O_3]\, dh\right)$$

Ratio of counts corresponding to heights h and h + $\Delta h$:

$R(\lambda, h, h + \Delta h)$

$$= \frac{(h + \Delta h)^2}{h^2} \quad \frac{n_h}{n_h + \Delta h} \cdot \exp(-2\sigma_{O_3}(\lambda)\,[O_3]\,\Delta h)$$

Hence $\sigma_{O_3}(\lambda)\,[O_3]\,\Delta h$ can be found assuming $n_h$, $n_{h + \Delta h}$

Alternatively, the ratios for wavelengths provides

$$\exp[-2\,(\sigma_{O_3}(\lambda_1) - \sigma_{O_3}(\lambda_2))\,[O_3]\,\Delta h]$$

and hence knowing $\sigma_{O_3}(\lambda_1)$ and $\sigma_{O_3}(\lambda_2)$, $[O_3]$ can be found.

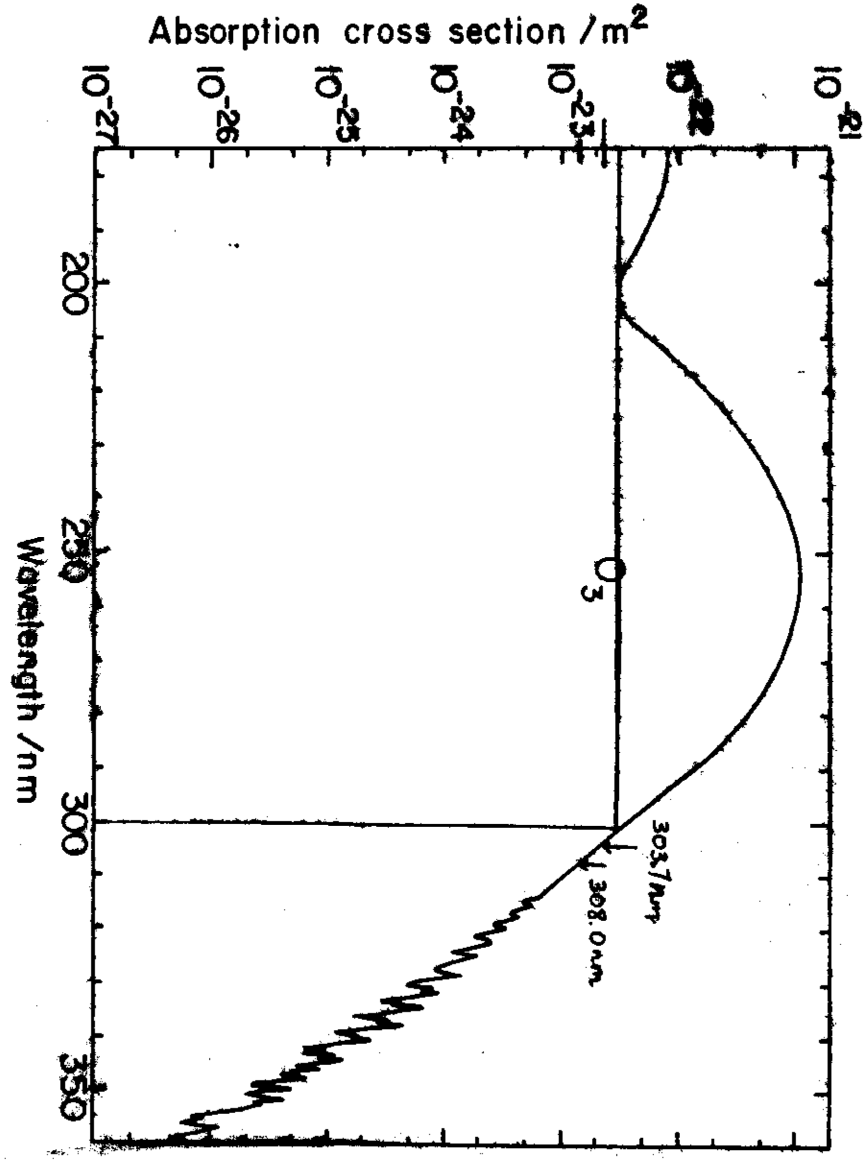
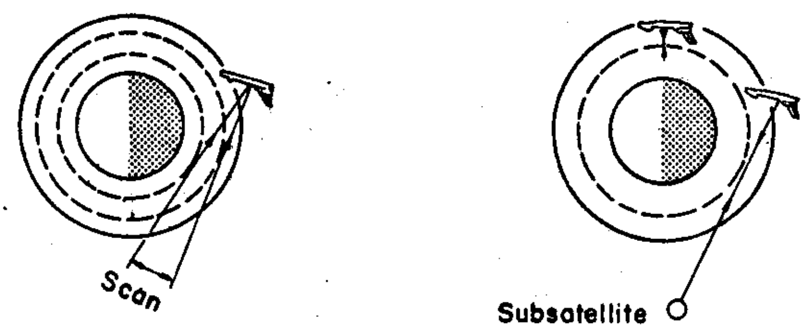



Fig. 10




Passive (Radiometer)

Active (Laser)

Remote Sensing of Atmosphere