



# Characterization of aircraft engine soot: unique properties and clouds impact

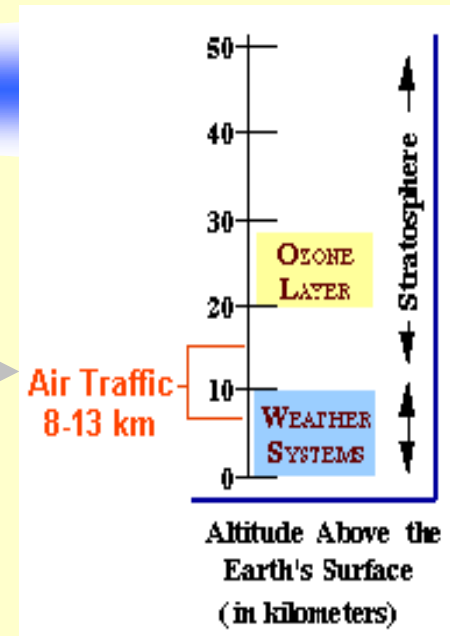
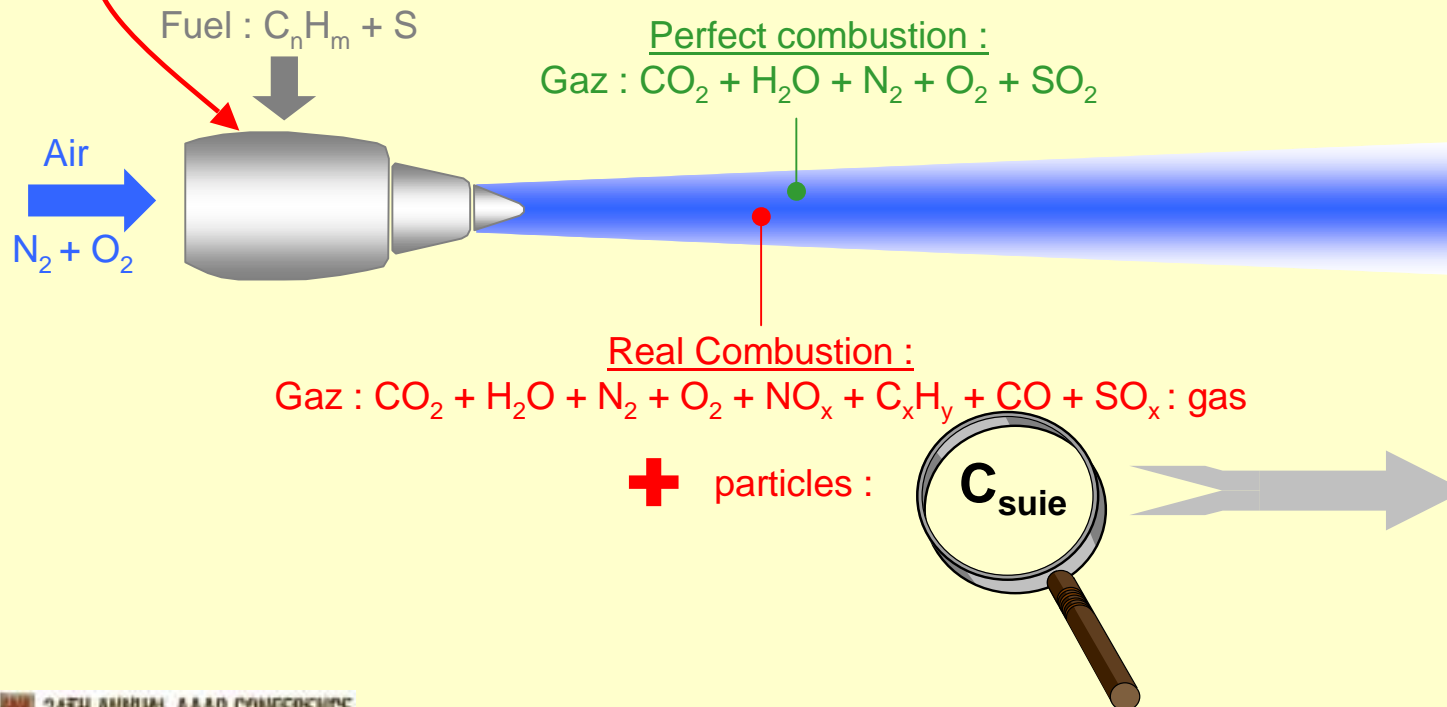
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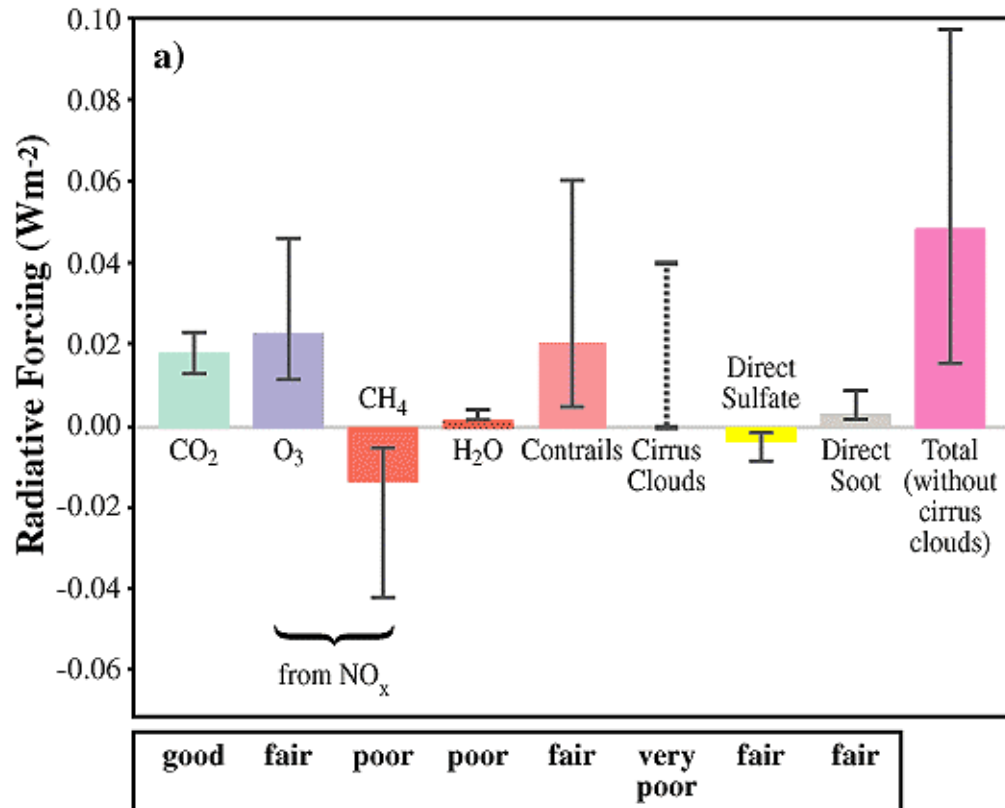
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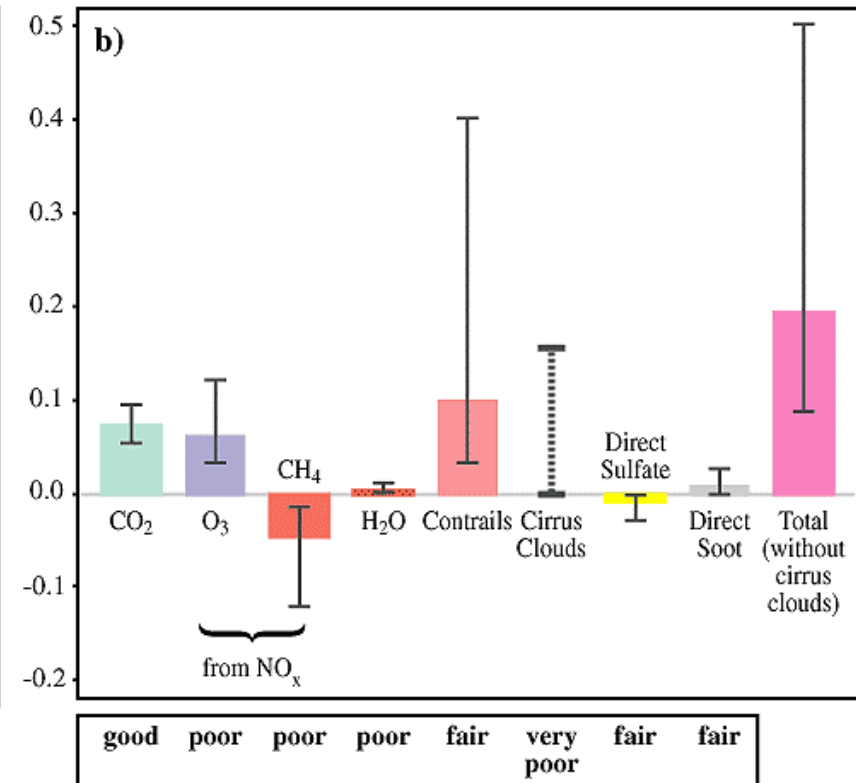




Radiative Forcing from Aircraft in 1992



Radiative Forcing from Aircraft in 2050



- ➡ Significant role of aircraft black carbon (BC) emission on contrail and cirrus formation leading to a positive radiative forcing and climate changes
- The ceaseless increase of the aircraft traffic ➡ very large uncertainty of this effect for the future years



The low ability to predict climatic consequences (only qualitative estimates)

- ▶ The paucity of data about the physicochemical properties of aircraft engine soot

Most of studies, based on laboratory-generated soot particles

- ▶ show a large variation in their nucleation properties and reactivity.

**This study is devoted to the comparison of laboratory soot / engine soot:**

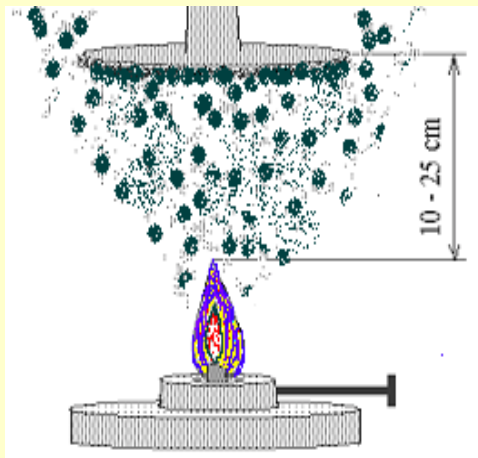
- morphology,
- microstructure,
- chemical composition,
- hygroscopic properties

⇒ **determine the mechanisms responsible for the formation of CCN (contrails, clouds cirrus)**



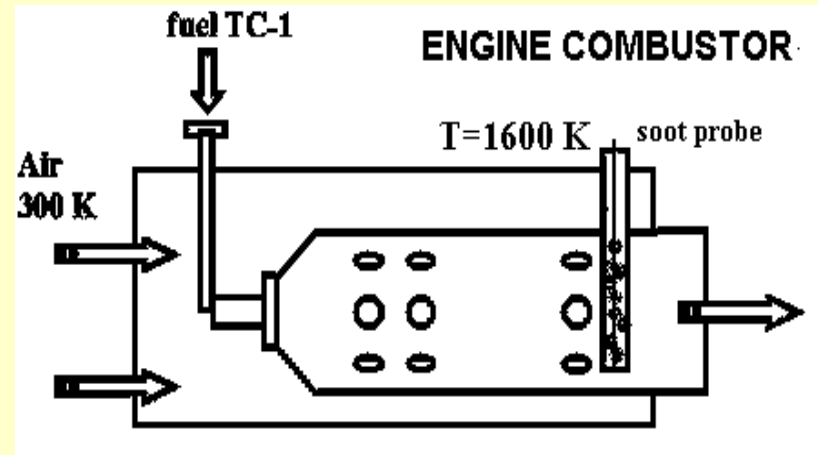
Aviation kerosene TC1 sulfur content:  $1100 \mu\text{g.g}^{-1}$

TC1 laboratory surrogate soot



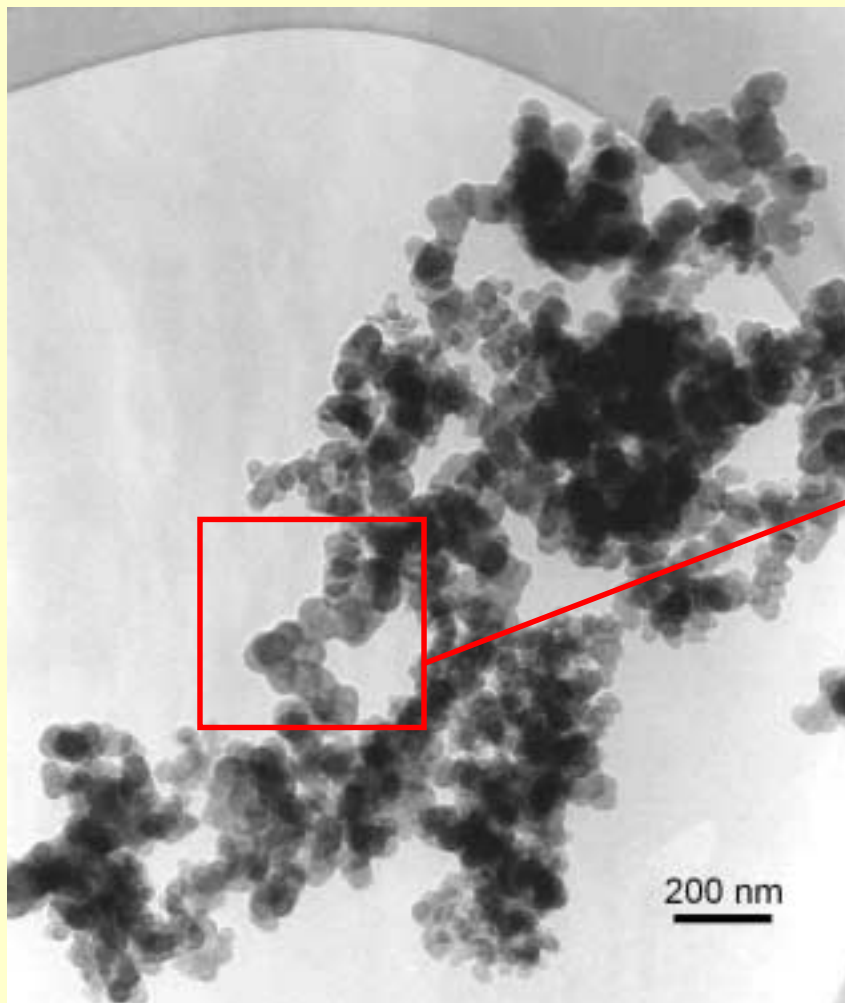
Laboratory oil lamp

TC1 engine soot

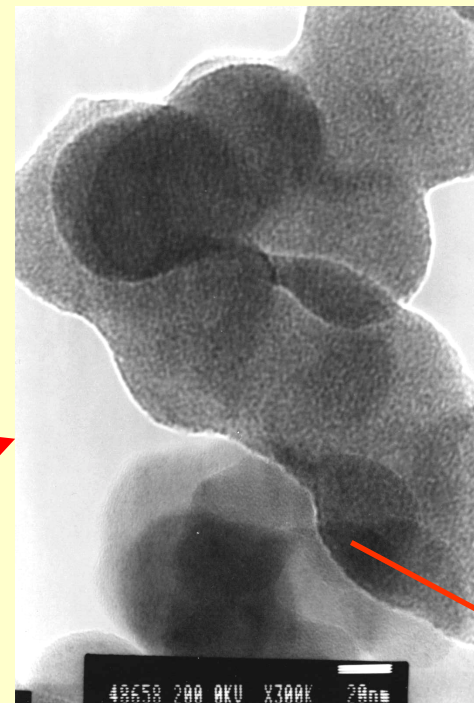


Engine operates so as to simulate real cruise conditions

Engine combustor	$T_{\text{inlet}}(\text{K})$	$T_{\text{outlet}}(\text{K})$	Air-to-fuel ratio	Pressure (atm)	Comment
D30-KU	300	1250-1450	4 - 4.5	3 - 5	Engine operating on Tu-134



Transmission Electron Microscope : JEOL JEM 2000 FX  
(resolution: 2.8 Å at 200 keV)

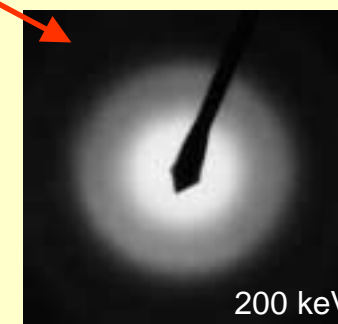


spherical particles



size distribution :  
d ~ 40-50 nm

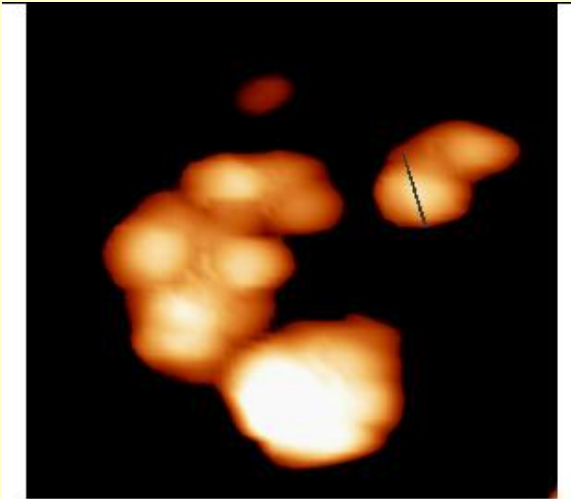
Diffraction



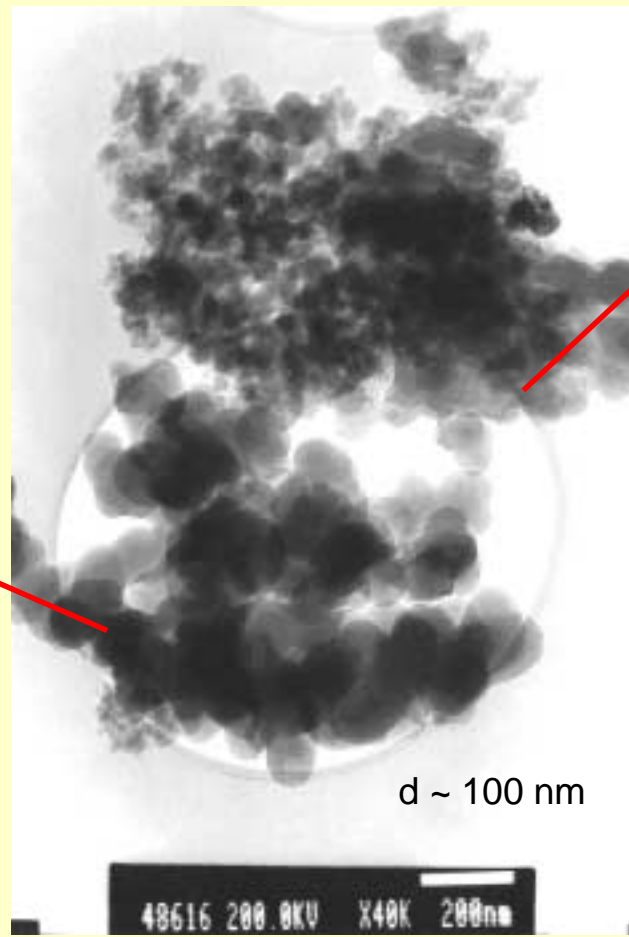
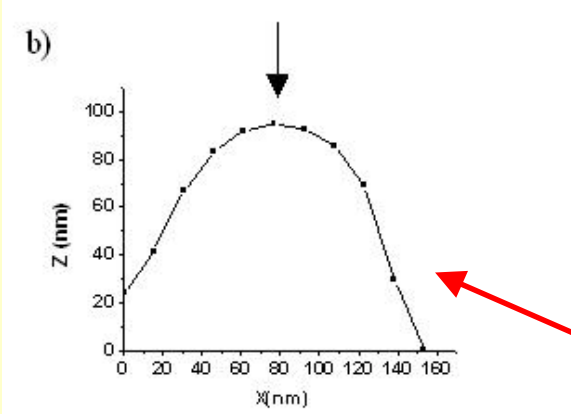
diffuse rings



- amorphous carbon  
- not well cristallized



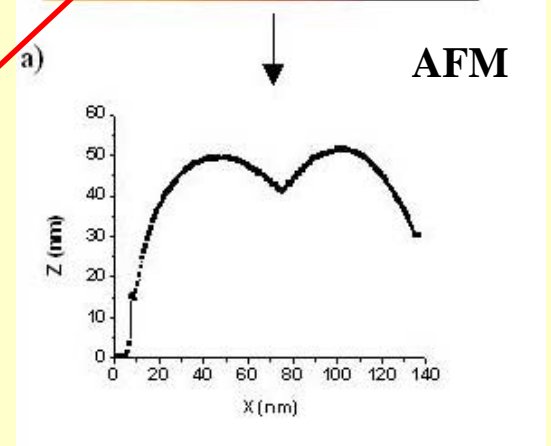
2 size distributions



d ~ 100 nm

48616 200.0KV X40K 200nm

TEM: JEOL JEM 2000 FX

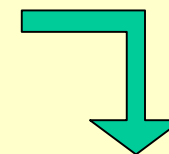
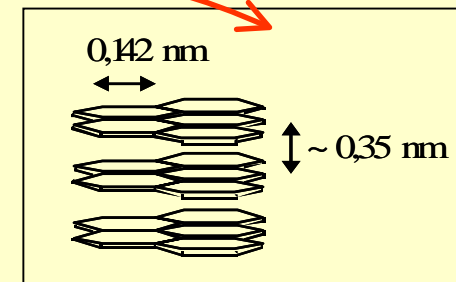
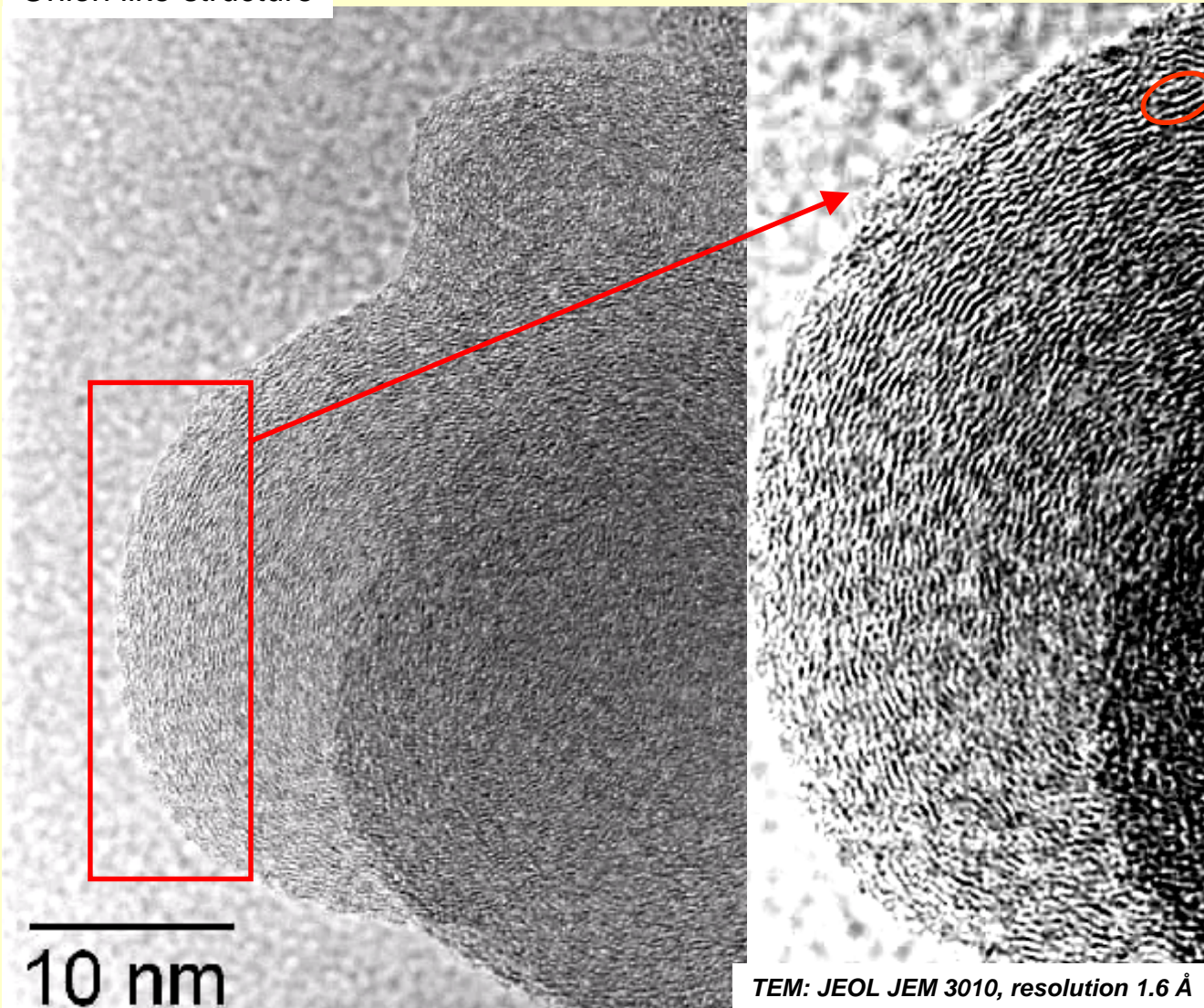


AFM

size distribution :  
d ~ 40-50 nm

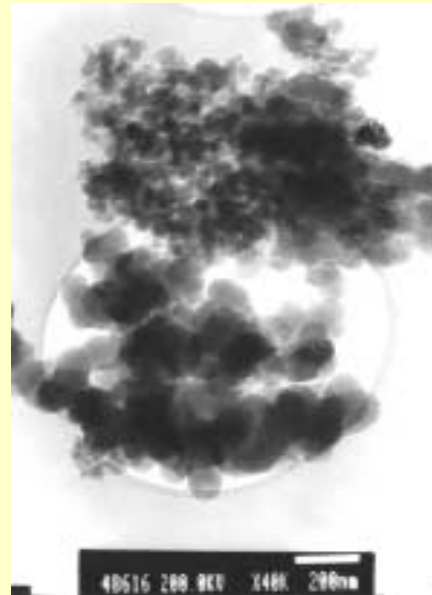
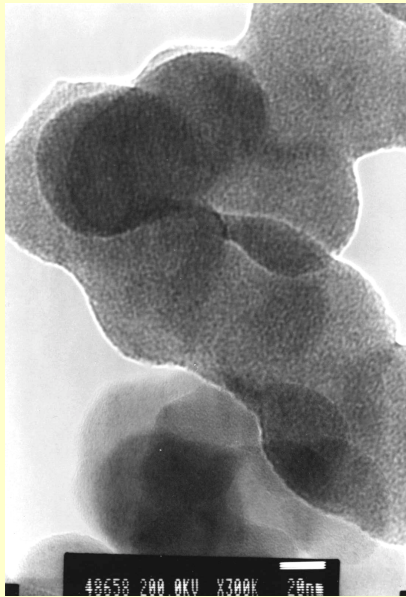


Onion like-structure

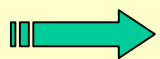


graphitic structure  
 $d_{100} = 2.03 \text{ \AA}$   
 $d_{002} = 3.36 \text{ \AA}$





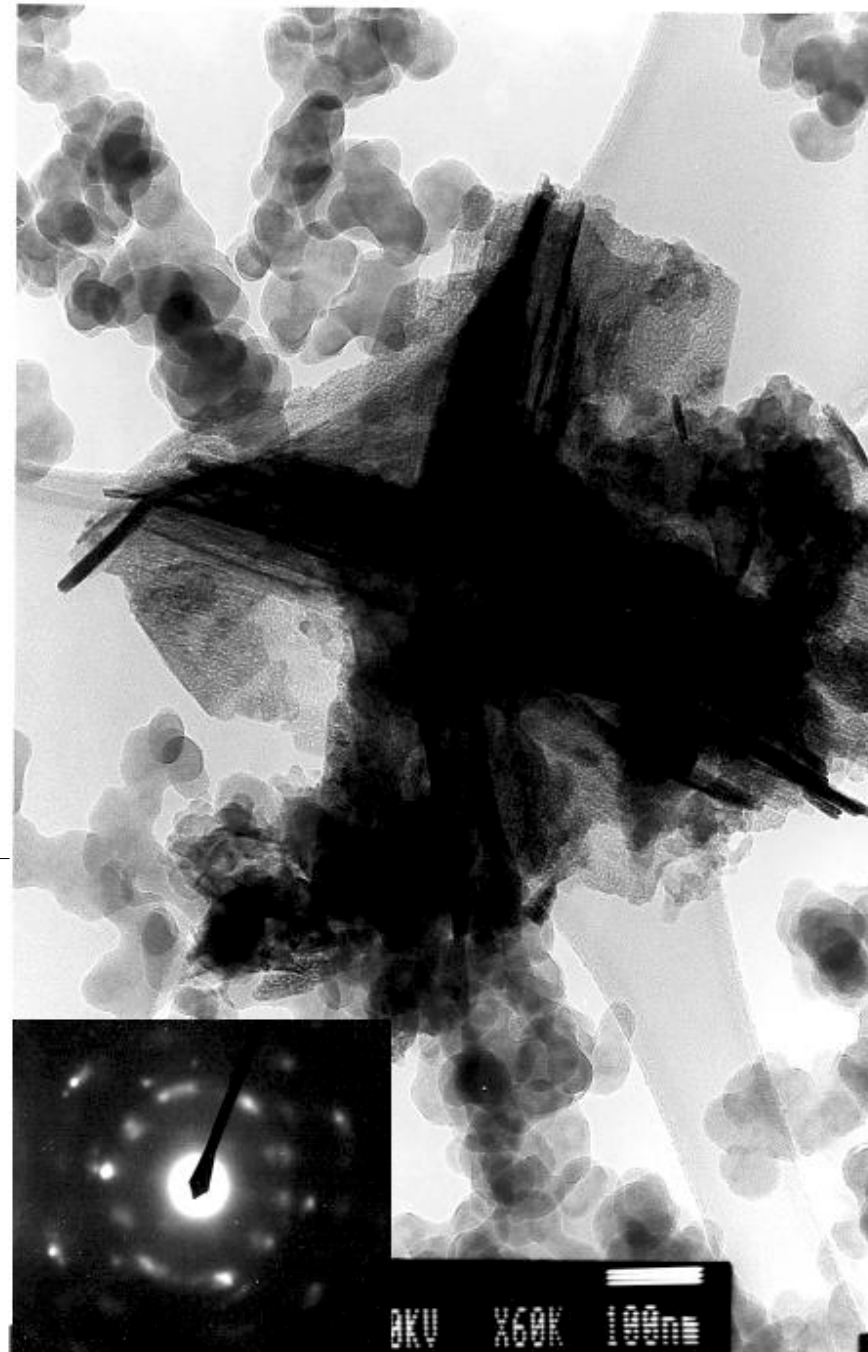
	C (weight %)	O (weight %)	S (weight %)
Laboratory soot	98-99	1-2	-
Engine soot	98	1.6	0.2



for both soot, the main fraction is essentially composed of amorphous spherical carbon particles

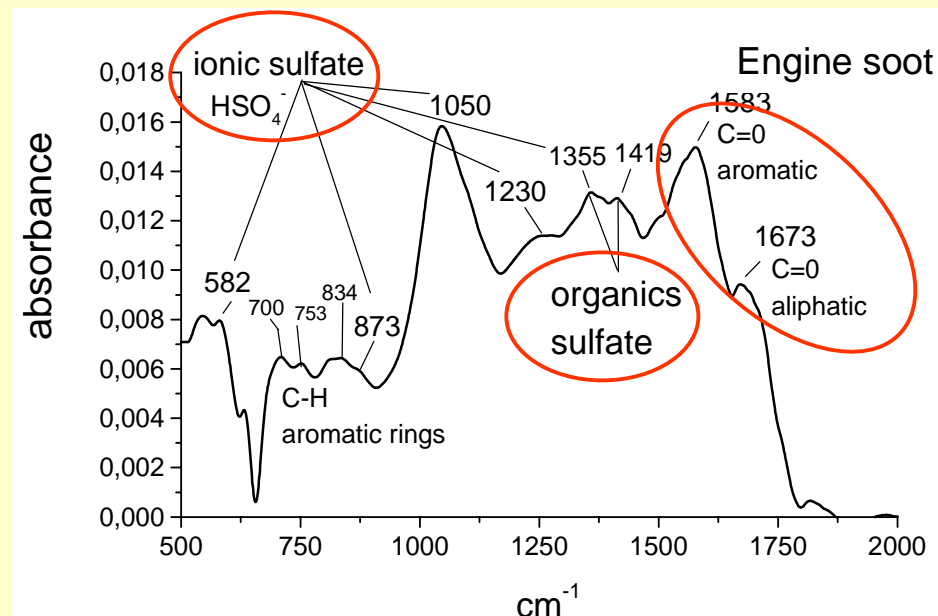
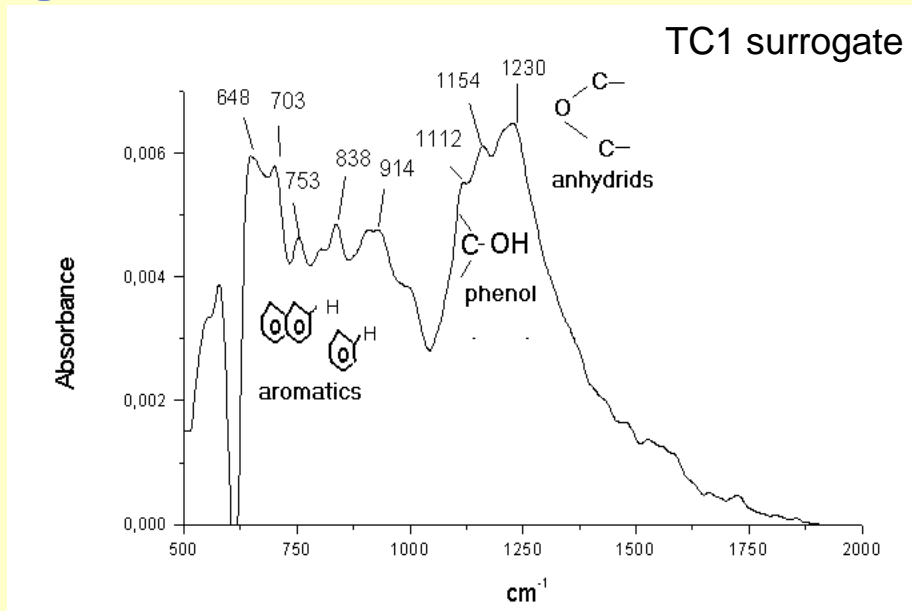
- Presence of dark and well-crystallised impurities
- Diffraction pattern analysis → Iron oxide ( $Fe_3O_4$ )
- Chemical composition (by EDS):

Conc. (wt %)	C	O	S	Fe
Engine soot With impurities	43-54	11	2	33-43





FTIR: surface functional groups



SURROGATE ; ENGINE	Bands (cm <sup>-1</sup> )	Hydrophilicity
CH deformation, aromatics	650-920	Low
-C-O-C- anhydrides, aryls	1230	Medium
C-OH stretch, phenols	1154,1112	Medium
-O- aromatic ester	1154, 1112	Low
O-H stretch, hydroxyl	3290	High

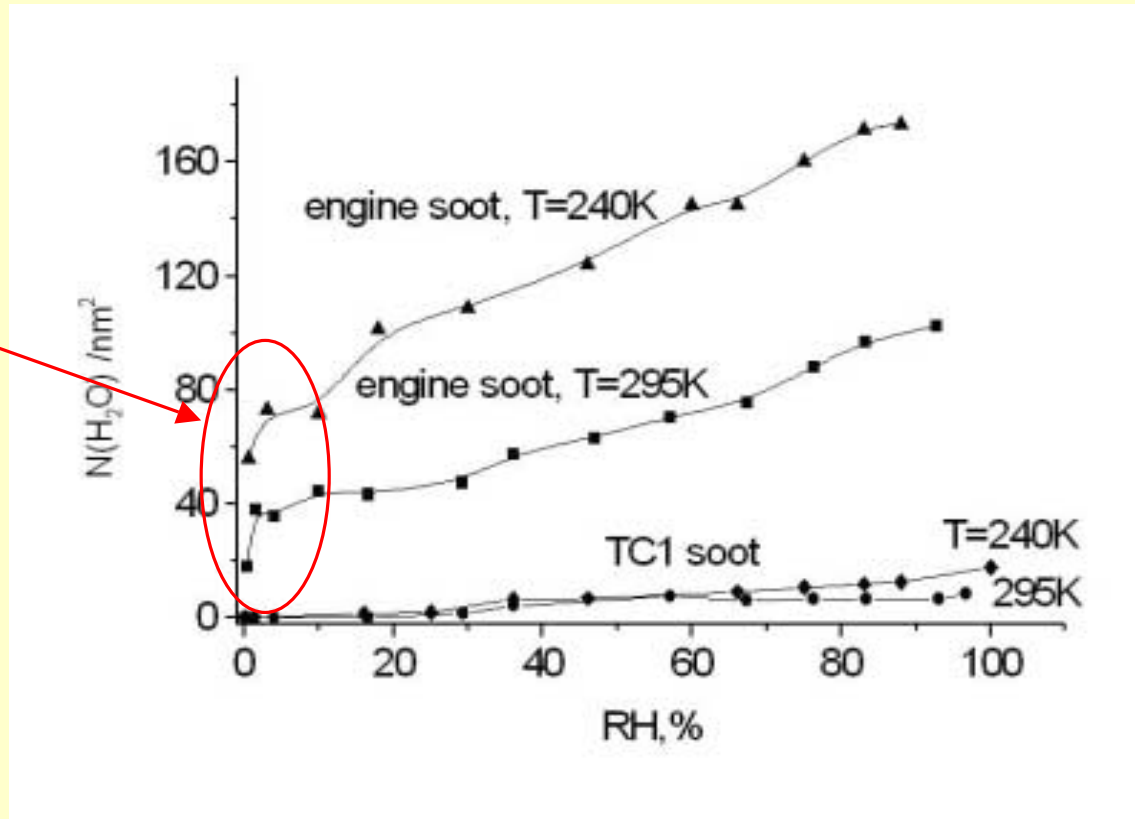
ENGINE ONLY	Bands (cm <sup>-1</sup> )	Hydrophilicity
<b>C=O carbonyl, aliphatic</b>	1673	High
<b>C=O carbonyl, aromatic</b>	1583	High
<b>HSO<sub>4</sub><sup>-</sup> ion</b>	1355,1230 1050, 878, 582	High
<b>Organic sulfates</b>	1350, 1420	High

**Engine soot has much more hydrophilic surface functional groups than the surrogate soot**



- surprisingly high level of water adsorption on engine soot at low RH and at T = 295 K

→ initial adsorption on the strongest active sites (surface ionic and organic sulfates).



- adsorption on engine soot  $\gg$  TC1 surrogate soot. (TC1 isotherm shape corresponds to an hydrophobic mat.)
- The amorphous carbon main fraction of soot is not responsible of the hydrophilicity
- Only the fraction of impurities of engine soot can act as Cloud Condensation Nuclei.



- Combustion conditions within an aircraft engine have a drastic influence on engine soot properties.
- According to its chemical composition and structure, engine soot is a mixture of a relatively hydrophobic main fraction almost free of impurities and a more hydrophilic fraction containing impurities.
- A significant amount of sulfur is accumulated within the aircraft engine on the soot surface as derivatives of sulfuric acid. Together with water soluble organics, they are responsible of both the highly hygroscopic nature of the engine soot and its ability to act as CCN for contrails.