Filter Transmittance Measurements: Experience with IMPROVE and Plans for CSN

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103 YEARS AGO ...

METHODS OF MEASURING ATMOSPHERIC POLLUTION BY SUSPENDED MATTER.[1]

BY DR. JOHN S. OWENS, F.R.G.S., F.G.S., A.M.I.C.E., M.R.S.I.

IN this paper some of the different methods which may be used to measure the degree of pollution of the air by smoke, dust, and other suspended impurities are considered, and their relative merits discussed.

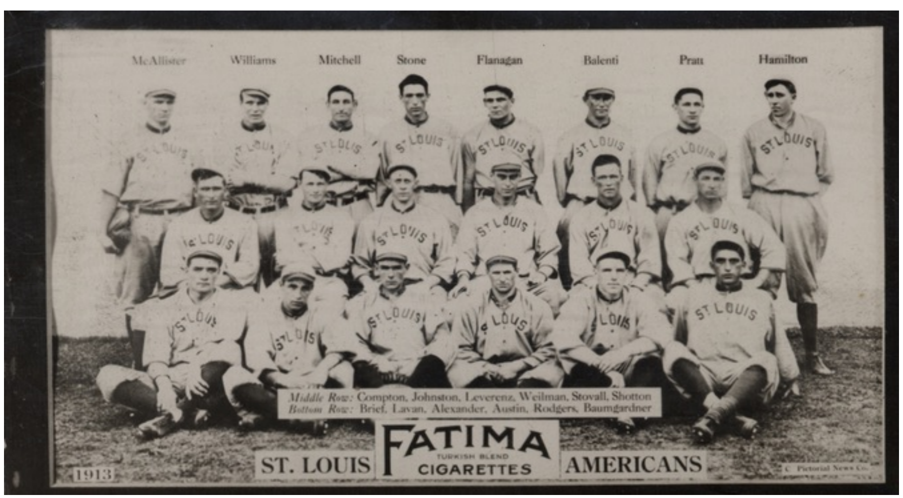
In 1911, at the International Conference on Smoke Abatement held in London, it was proposed by the author that an attempt should be made to obtain by some uniform and standardised method comparative data as to the degree of pollution of the air at different parts of the United Kingdom. A committee was appointed at the conference to consider

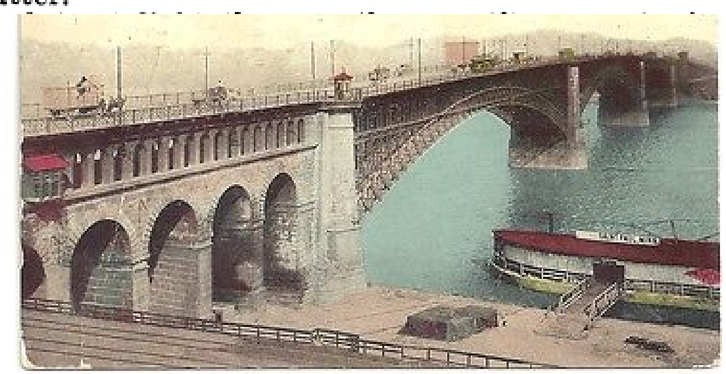
...of the deposit. The amount of deposit on a filter paper which is required to cause a definite discolouration is so small as to be hardly weighable. With some modification such as above indicated, and provision for obtaining a sufficient quantity of deposit to weigh with accuracy, this method promises to be very useful, as the time required for an observation is short, and the whole apparatus may be made in a compact form.

7. An optical method might be used by which the opacity of a column of air of a given length to a standard light is measured. This might be arranged to give quantitative results by preparing a scale of opacity from measurements taken on air with known amounts of suspended matter

...

method, the chief advantage being that, if practicable, it would permit an observation to be taken almost instantaneously, and would require no weighing to give the degree of pollution; it would not, however, ... find the nature and composition of deposited or suspended matter.

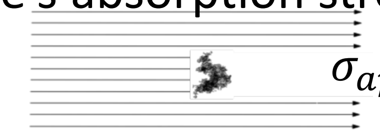




cient quantity of deposit to weigh with accuracy, this method promises to be very useful, as the time required for an observation is short, and the whole apparatus may be made in a compact form.

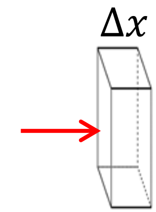
An example source of absorbing particles that was chosen not to embarrass anyone.

A **BACK-OF-THE-ENVELOPE** INTRO TO ABSORPTION BY SMALL PARTICLES

We quantify a particle's absorption strength by the area $\boldsymbol{\sigma_{ap}}\ (\boldsymbol{m^2})$ of its effective "shadow"  σ_{ap}, the absorption cross section.

Approximation: $\sigma_{ap} \propto m_p$ for small enough particles. The ratio $\boldsymbol{\frac{\sigma_{ap}}{m_p}}\ \left(\boldsymbol{\frac{m^2}{g}}\right)$ for a given particle type is called its mass absorption cross section (MAC).

Light fraction absorbed by thin aerosol layer:

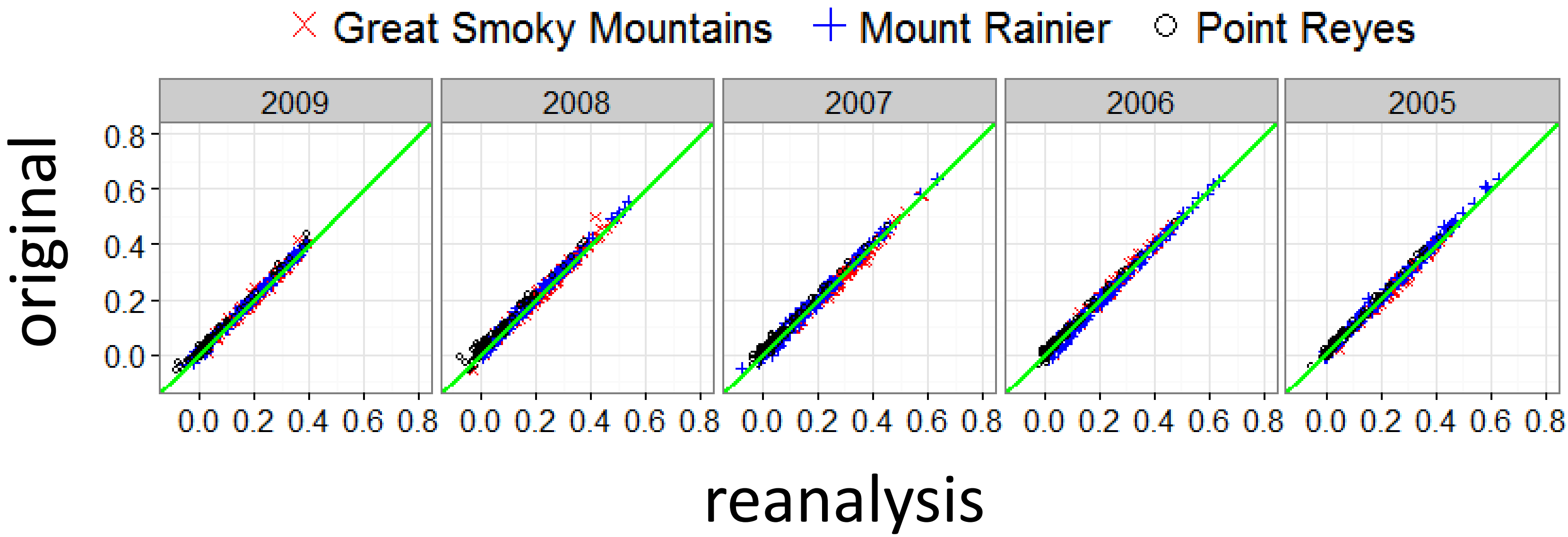


$$\frac{I_x - I_{x+\Delta x}}{I_x} \sim [PM]\left(\frac{g}{m^3}\right) \times MAC\left(\frac{m^2}{g}\right) \equiv \boldsymbol{b_{abs}(m^{-1})}.$$

Light fraction transmitted by aerosol column of length $x(m)$:

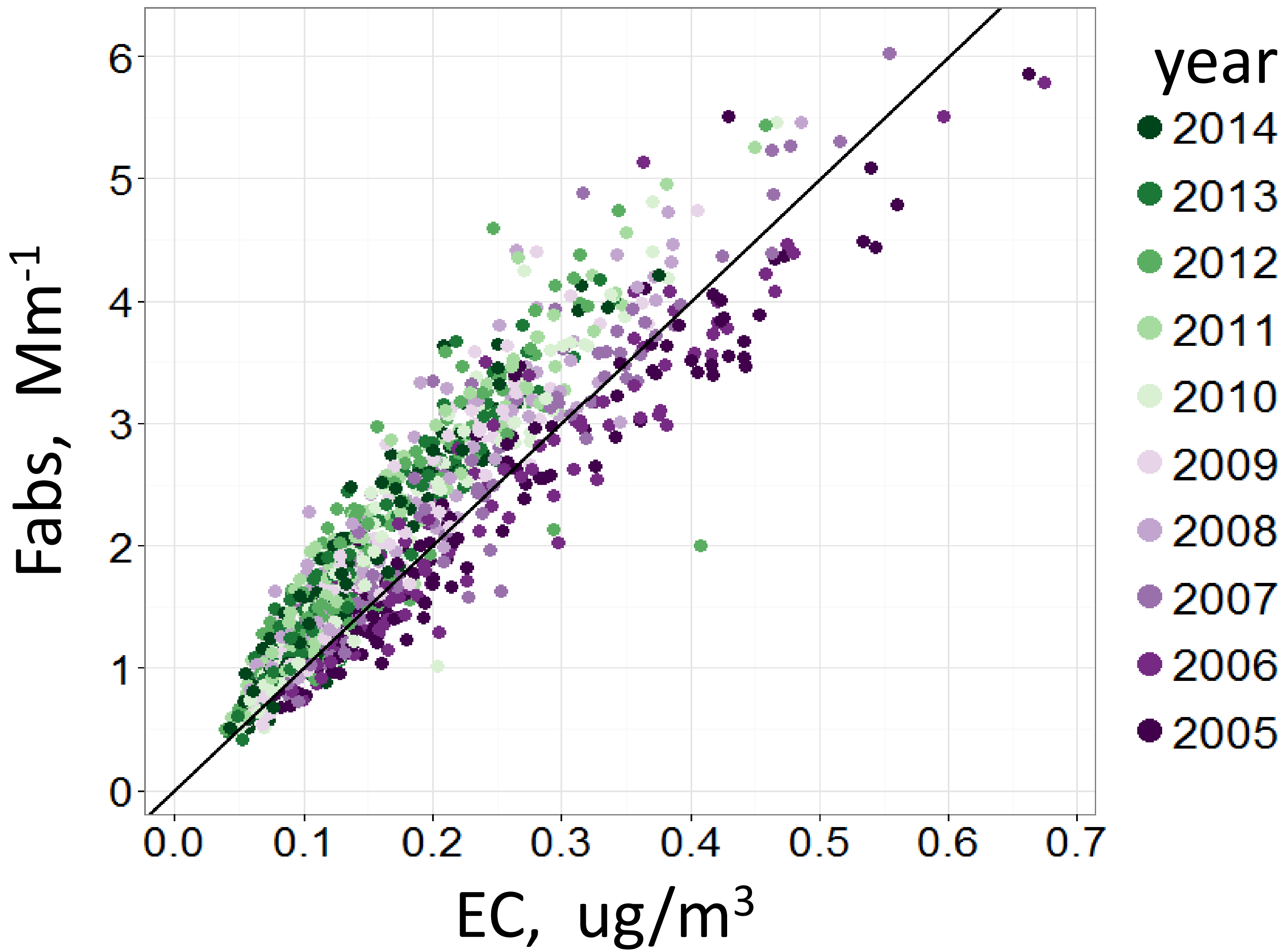
$$\boldsymbol{\frac{I}{I_0} = e^{-b_{abs}x}}.$$

IMPROVE

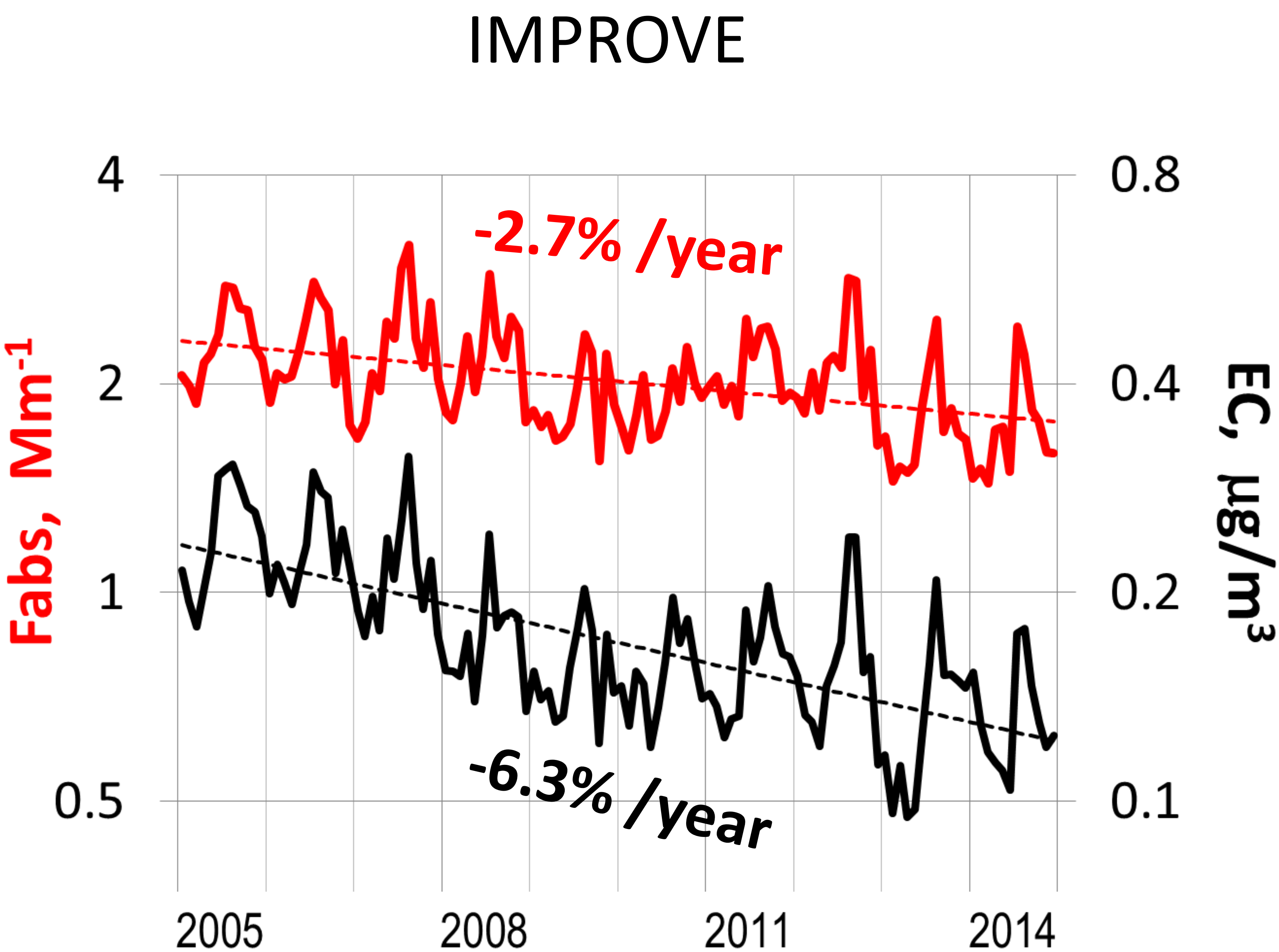


The non-destructive nature of optical analyses allows us to pull out and reanalyze archived samples to verify that our calibration has remained consistent through the years.

IMPROVE

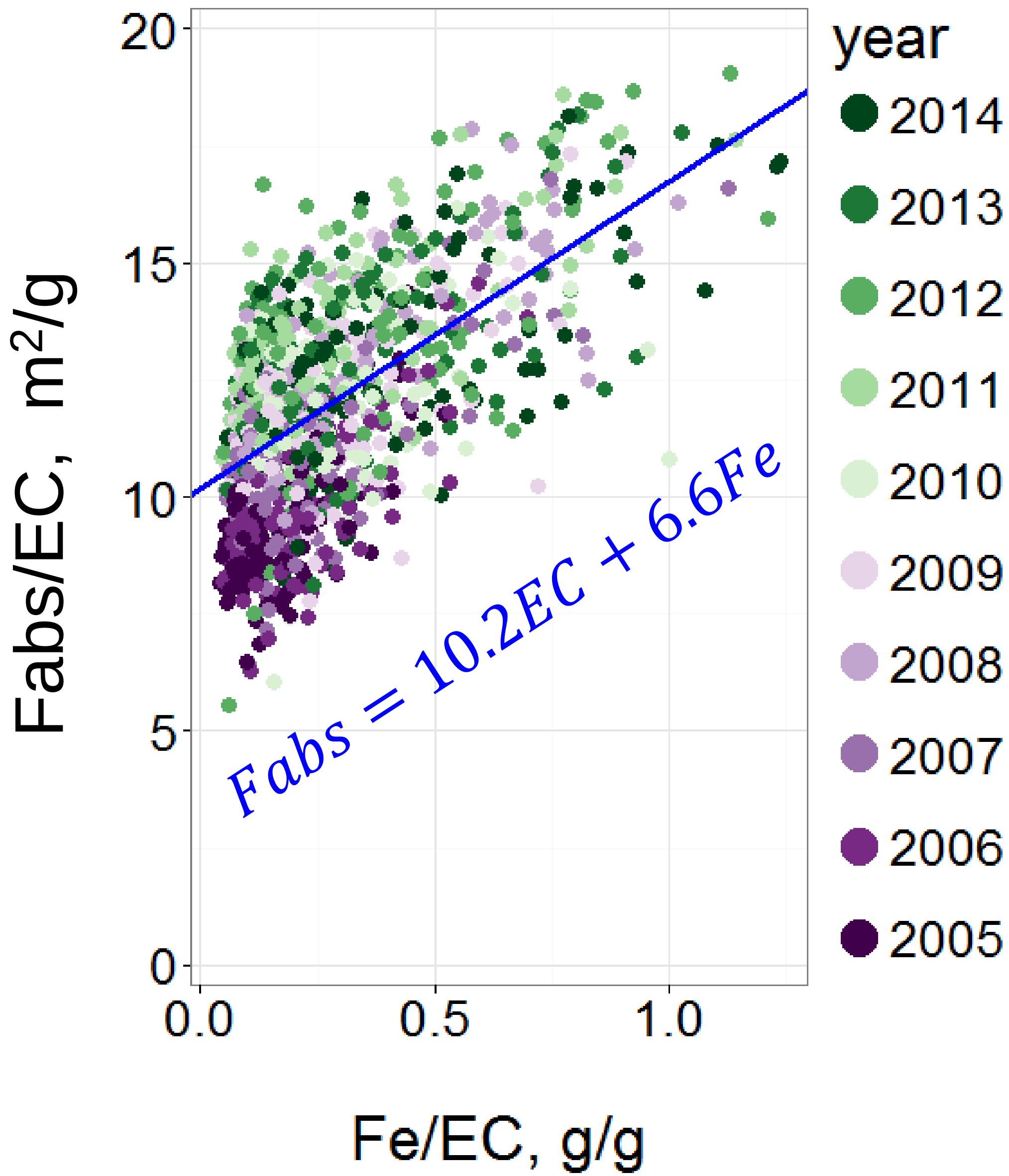


Fabs, Mm-1
EC, ug/m3
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
1
2
3
4
5
6
year
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005



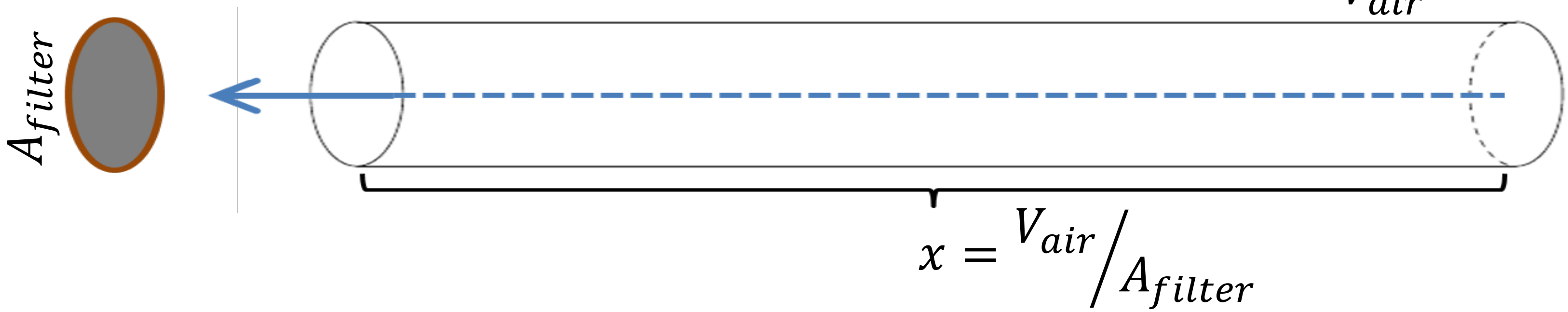
IMPROVE
-2.7% /year
-6.3% /year
Fabs, Mm-1
EC, µg/m3
4
2
1
0.5
0.8
0.4
0.2
0.1
2005
2008
2011
2014

IMPROVE



20
15
10
5
0
0.0
0.5
1.0
Fabs/EC, m2/g
Fe/EC, g/g
year
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005
$Fabs = 10.2EC + 6.6Fe$

Filter sampling concentrates three dimensions into two:



Mass of filter deposit = areal filter loading $\times A_{filter}$

Mass of sampled particles = air concentration $\left(\frac{particle\ mass}{air\ volume}\right) \times V_{air}$.

Sampling assumption: collected mass = sampled ambient mass, so
air concentration = $\left(A_{filter}/V_{air}\right)$ filter loading

Optical assumption/**Approximation**: the filter deposit has the same transmittance as the sampled air column,
$\frac{I}{I_0}(measured\ on\ filter) = e^{-b_{abs}x}$.

We can now solve for $b_{abs} \sim \frac{A}{V} ln\left(\frac{I_0}{I}\right)$.

It is conventional to express the dimensional quantities in mixed units:

air volume in m^3,

filter area in cm^2, and

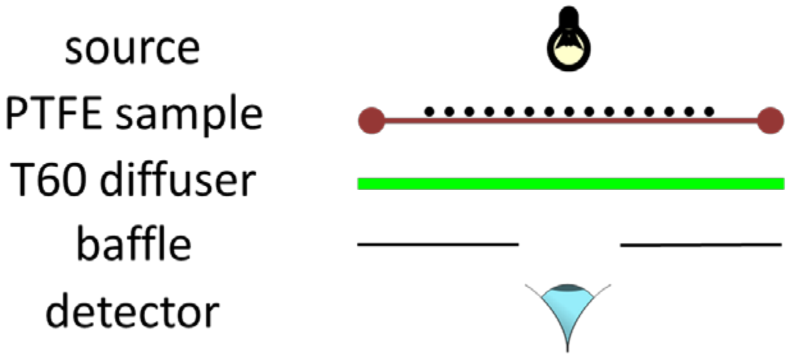
b_{abs} in *inverse megameters*, $Mm^{-1} = (10^6 m)^{-1}$.

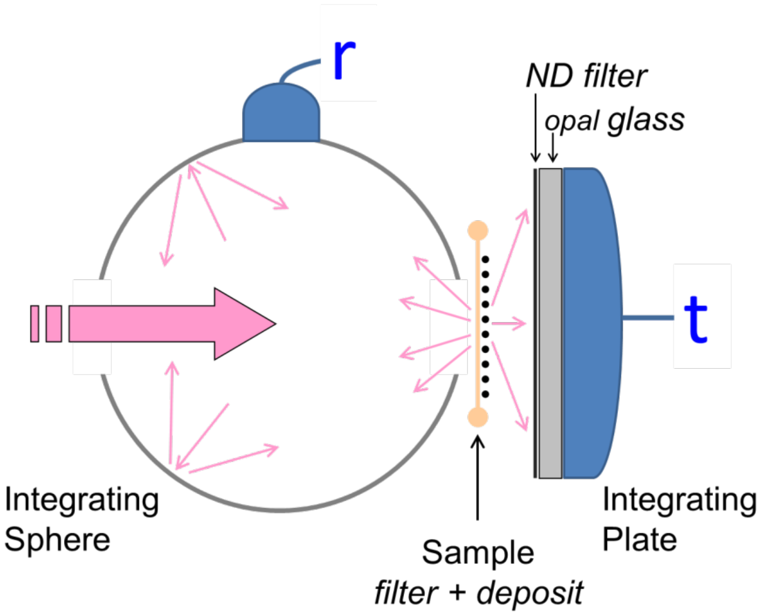
In these mixed units we have $\boldsymbol{b_{abs} \sim \frac{A}{V} 100 ln\left(\frac{I_0}{I}\right)}$.

The OT21 SootScan reports light absorption in “ATN units”, as $\boldsymbol{100 ln\left(\frac{I_0}{I}\right)}$.

OT21

HIPS

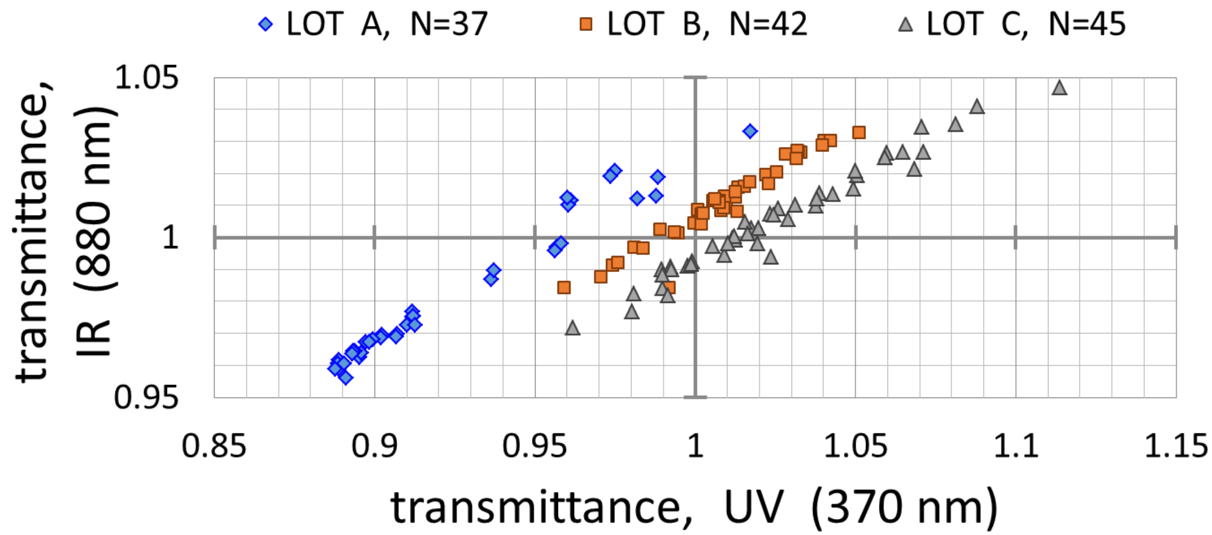




CSN

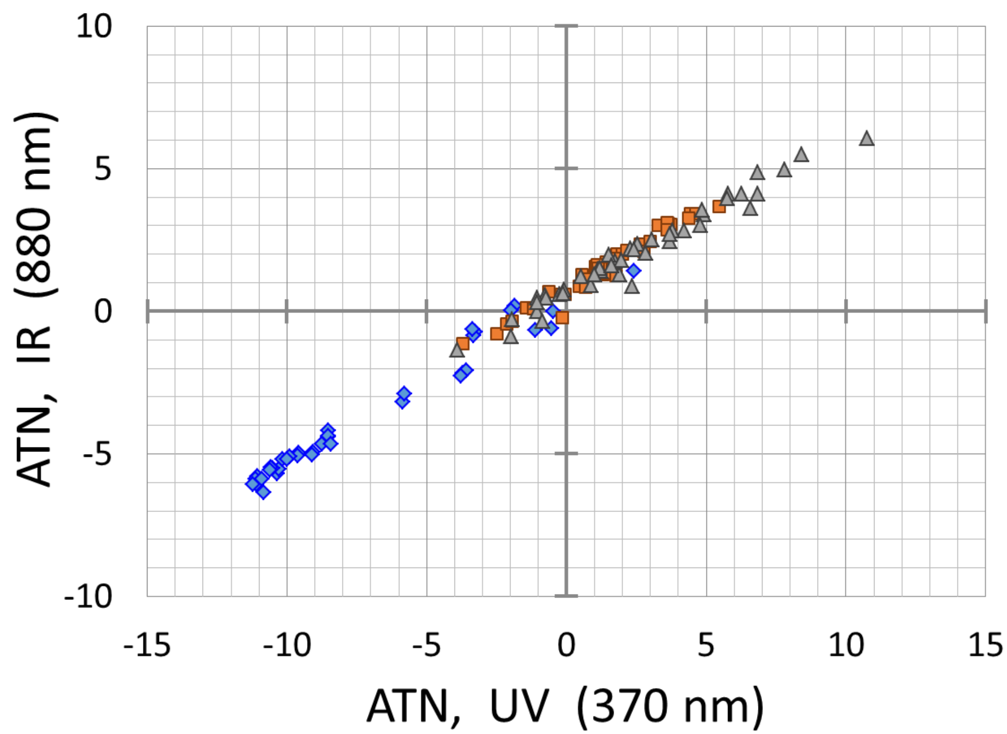
IMPROVE

raw blanks
(47 mm PTFE)



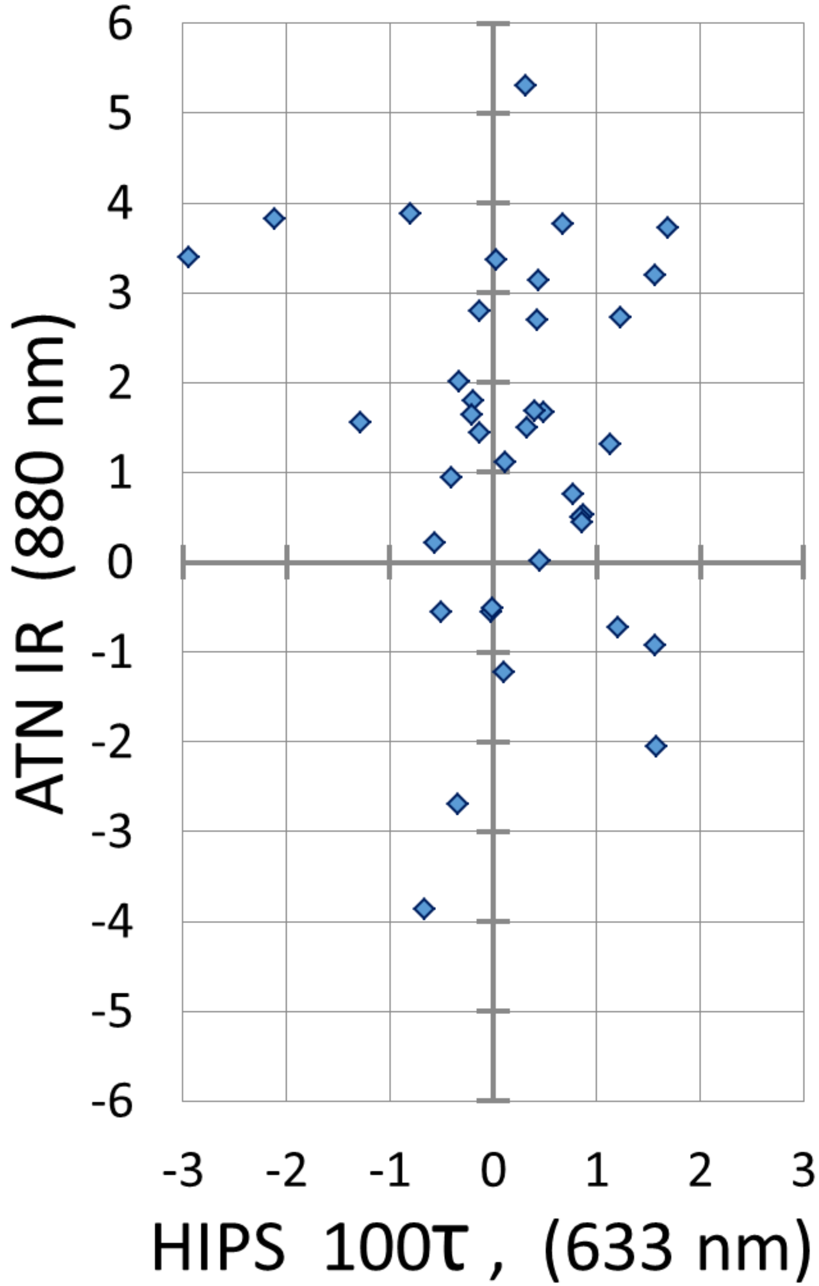
CSN blanks

blank-corrected
reading

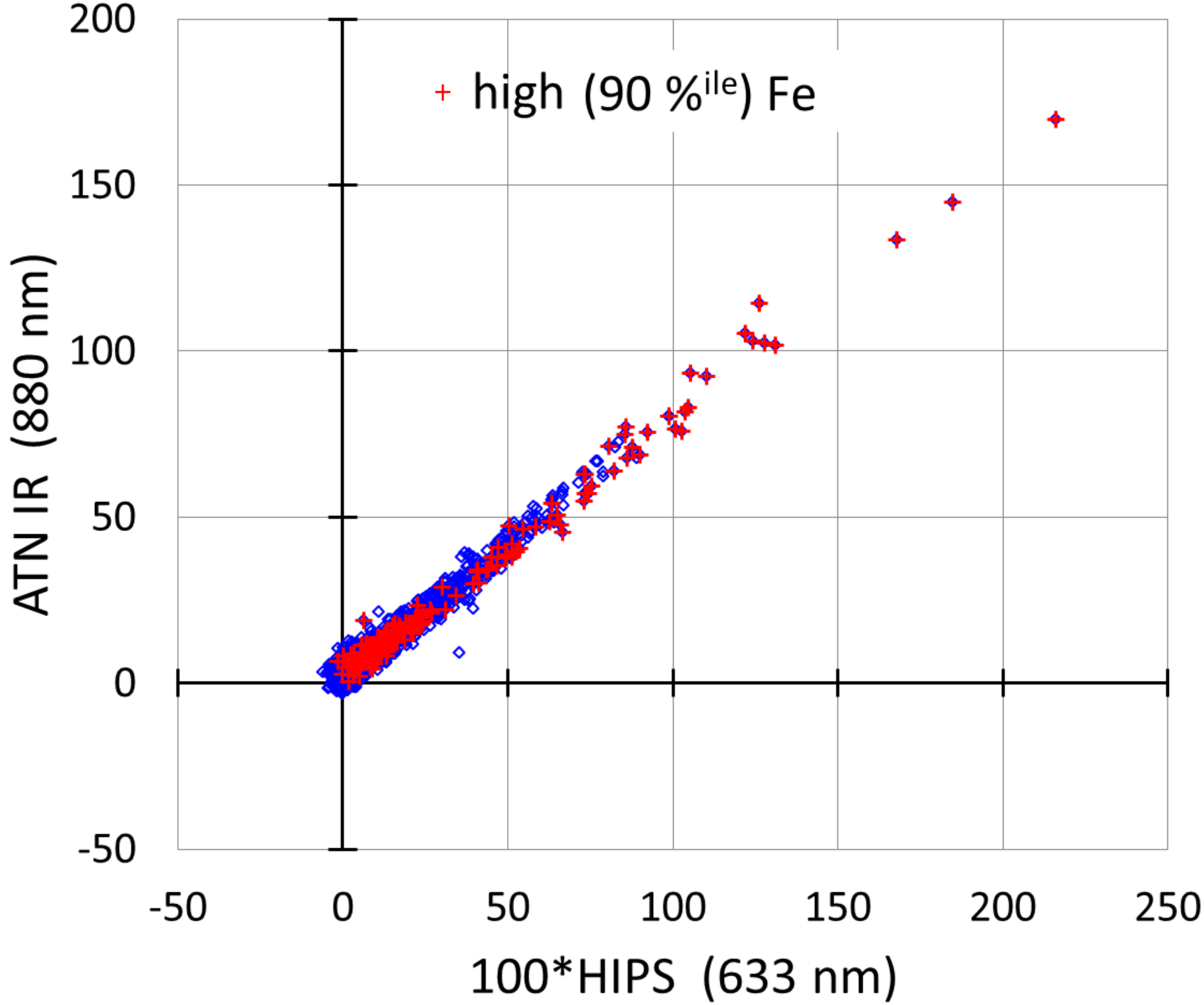


38 routine network field blanks from IMPROVE, 3/2016

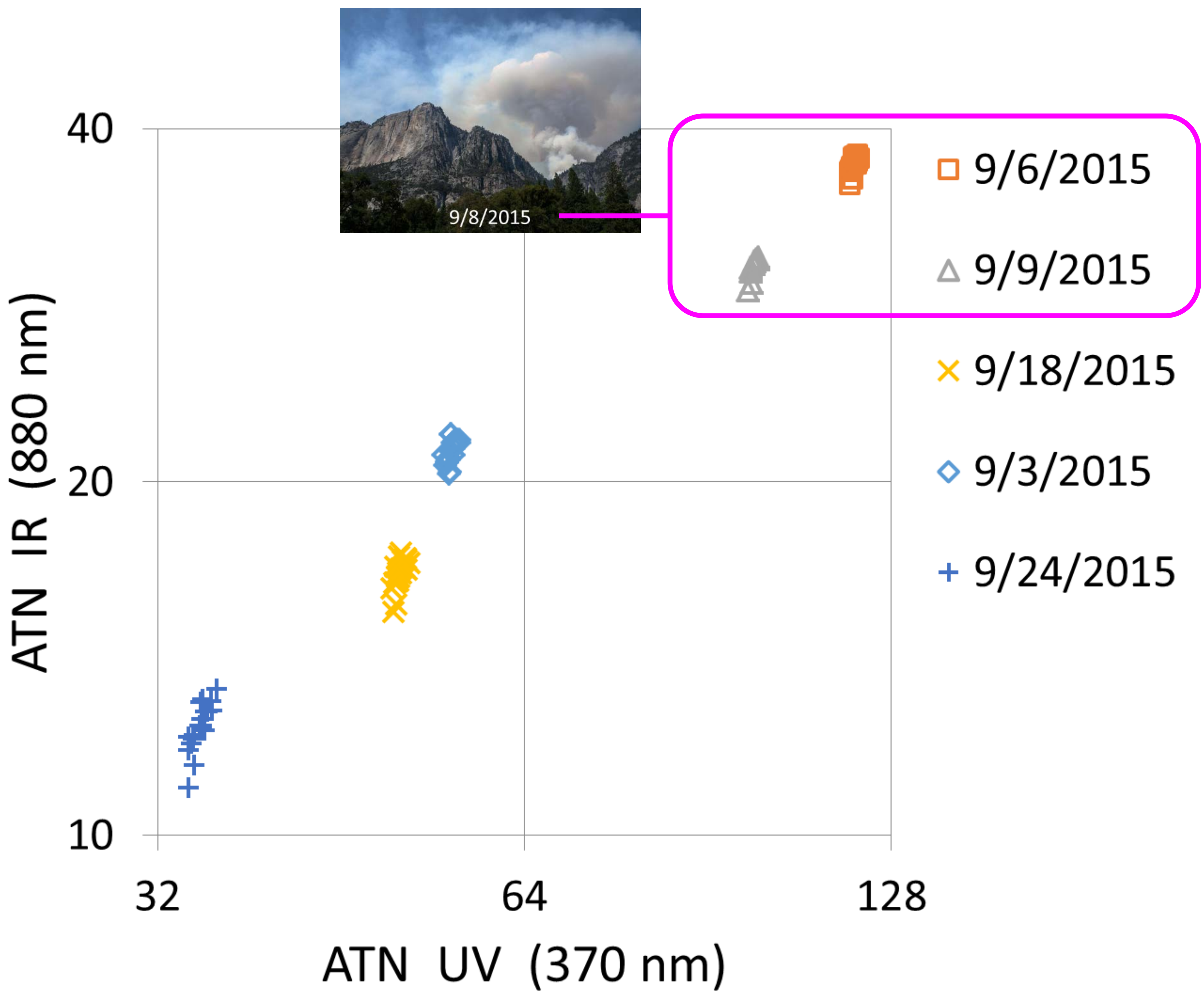
(25 mm PTFE)



IMPROVE samples, March 2016 (n = 1632)

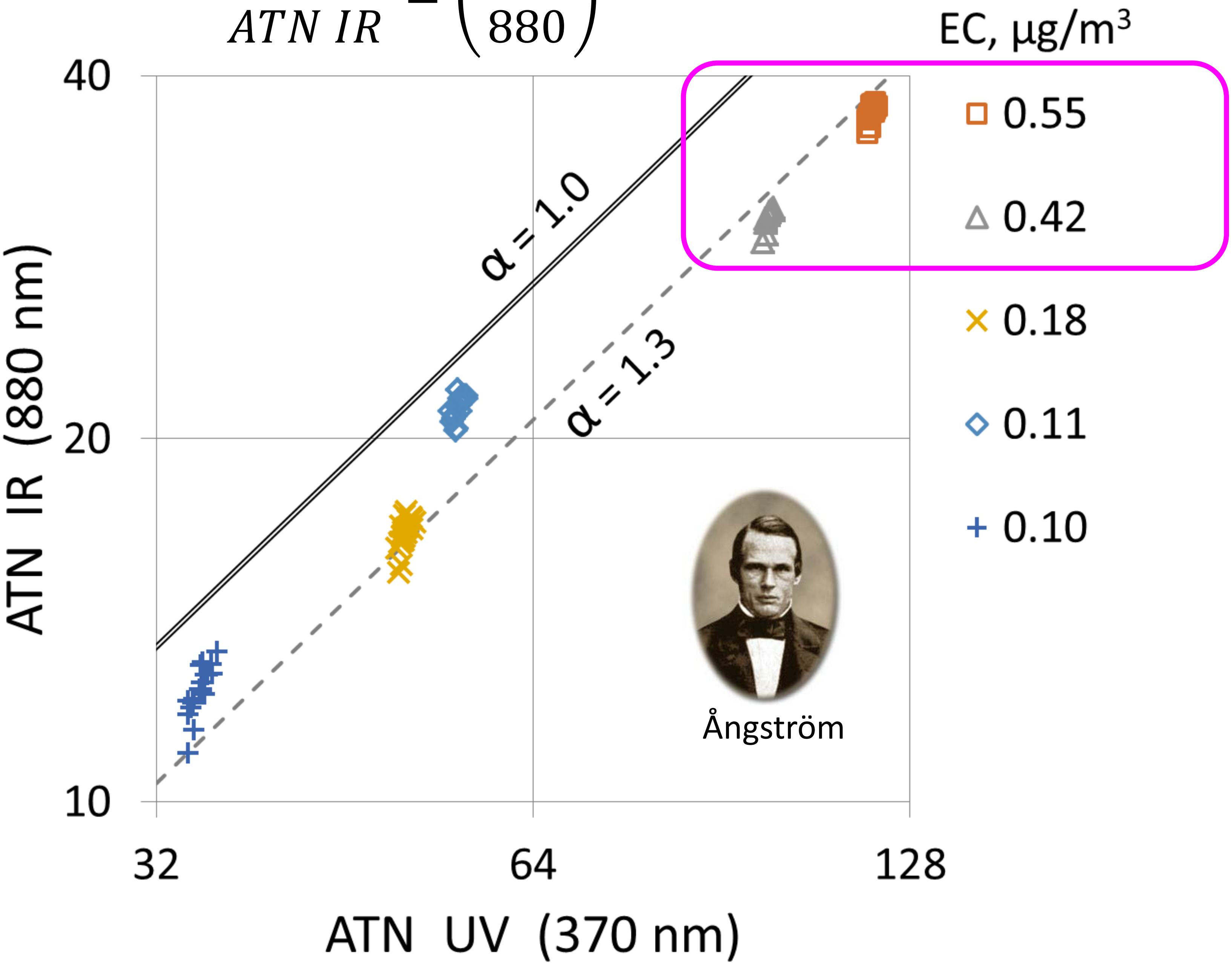


22 independent analyses of 5 IMPROVE samples from Yosemite, 9/2015



40
20
10
32
64
128
ATN IR (880 nm)
ATN UV (370 nm)
9/8/2015
9/6/2015
9/9/2015
9/18/2015
9/3/2015
9/24/2015

$$\frac{ATN\ UV}{ATN\ IR} = \left(\frac{370}{880}\right)^{-\alpha}$$



How much transmittance should we expect to see with the SootScan? We found that $b_{abs} \sim \frac{A}{V} ATN$, so $\boldsymbol{ATN \sim \frac{V}{A} b_{abs}}$.

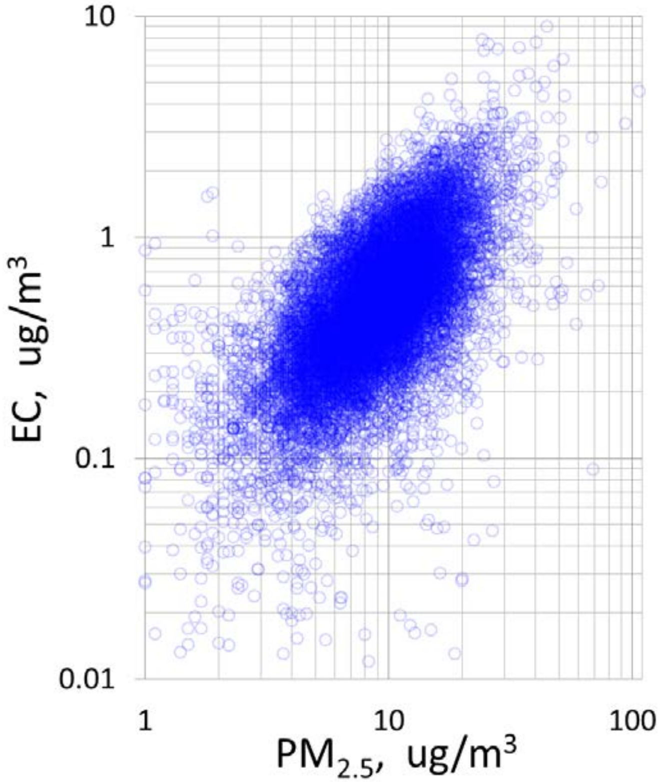
The **median** network concentration reported by CSN in 2012 was $\mathbf{[EC] \sim 0.5\ \mu g/m^3}$.

At the OT21-recommended $MAC = 17\ m^2/g$, this would yield $\boldsymbol{b_{abs}} =$
$= MAC \times [EC] \sim 8.5 \times 10^{-6} m^{-1}$
$\mathbf{= 8.5 Mm^{-1}}$.

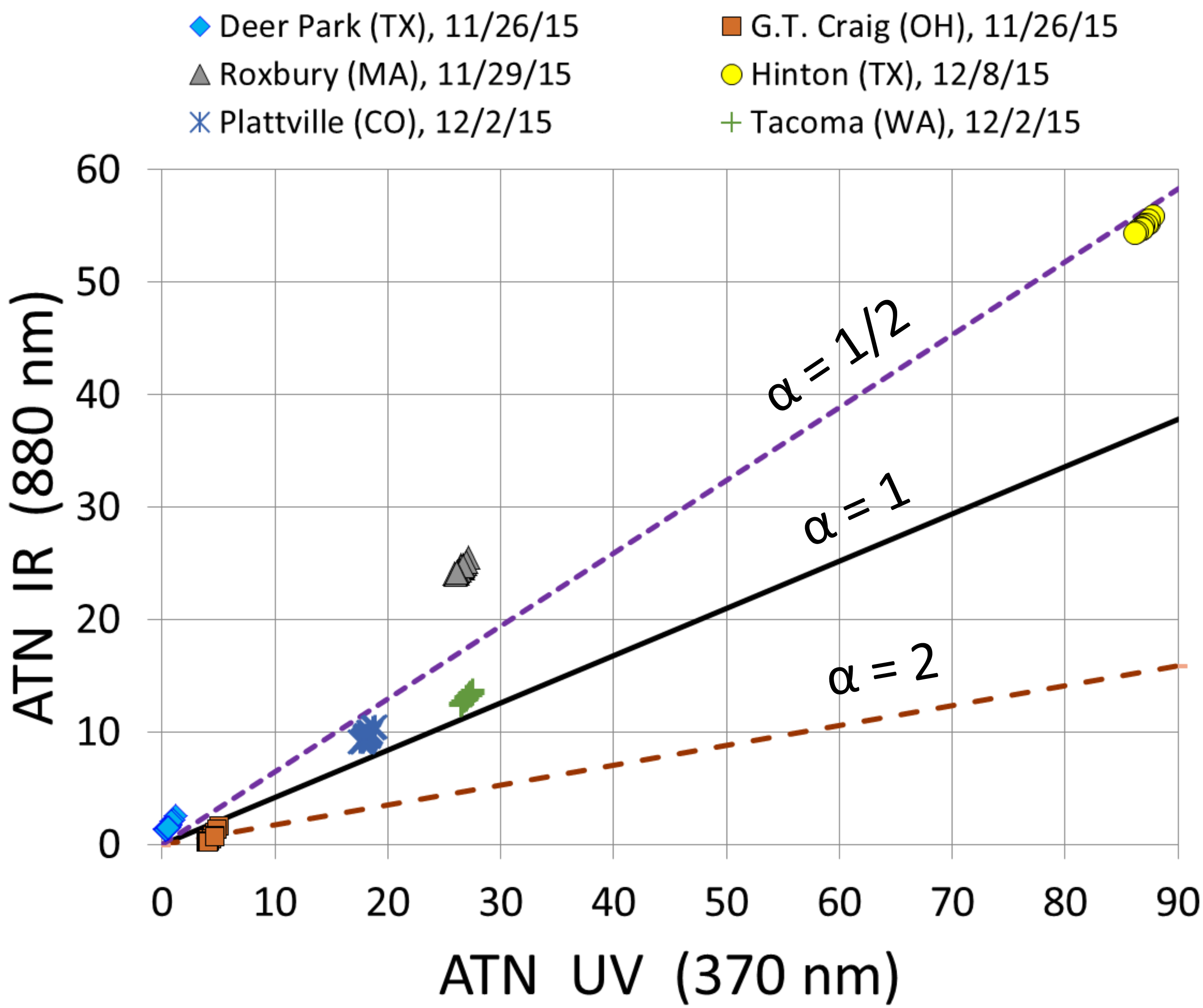
For a 47mm PTFE filter and the MetOne speciation sampler, we have nominal values of $\boldsymbol{V_{air} = 9.65\ m^3}$ and $\boldsymbol{A_{filter} = 11.3\ cm^2}$.

With all the previous *caveats*, we would then expect a reading of $\boldsymbol{ATN} \sim \frac{9.65}{11.3} \times 8.5 \boldsymbol{\sim 7.3}$.

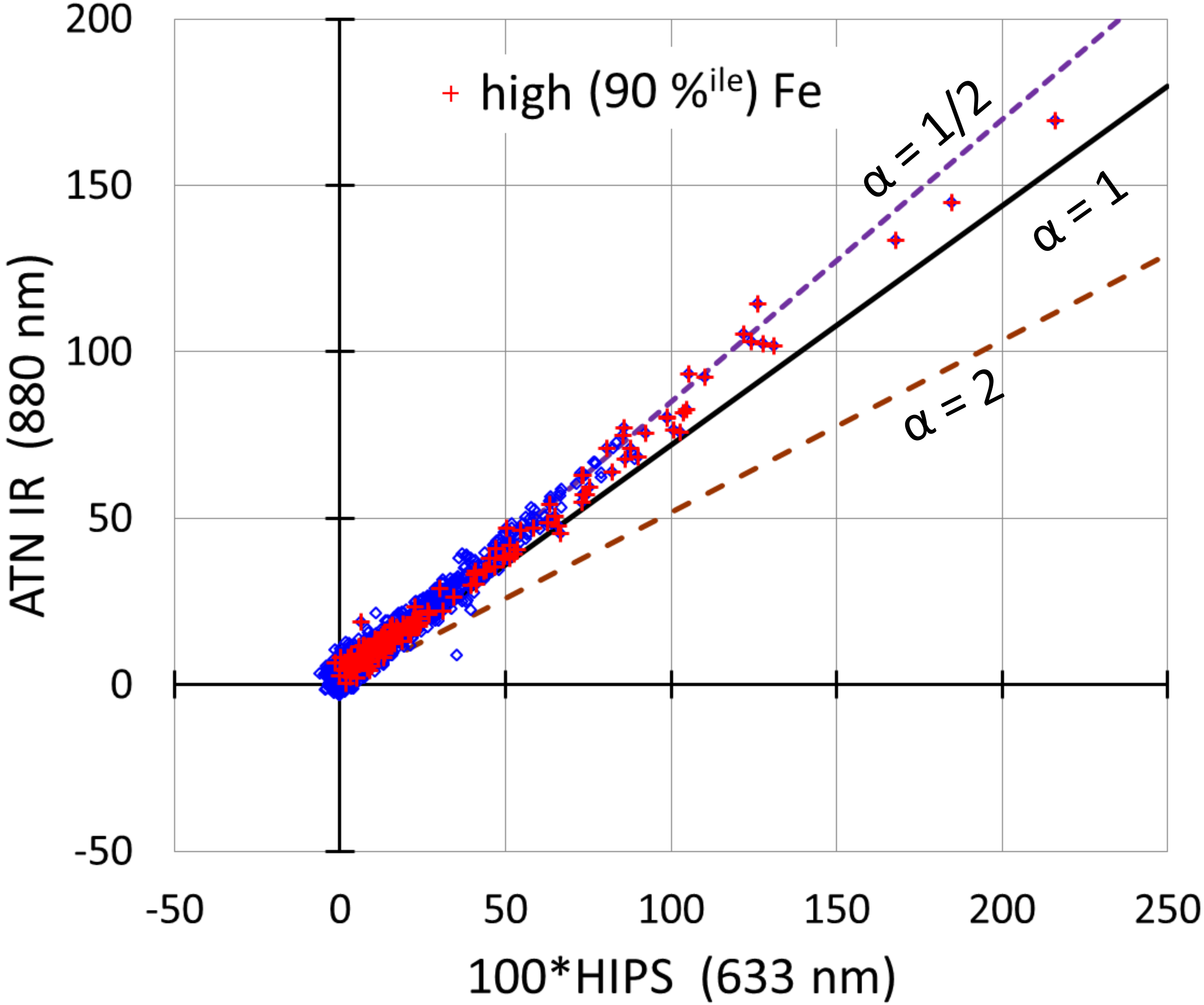
CSN, 2012



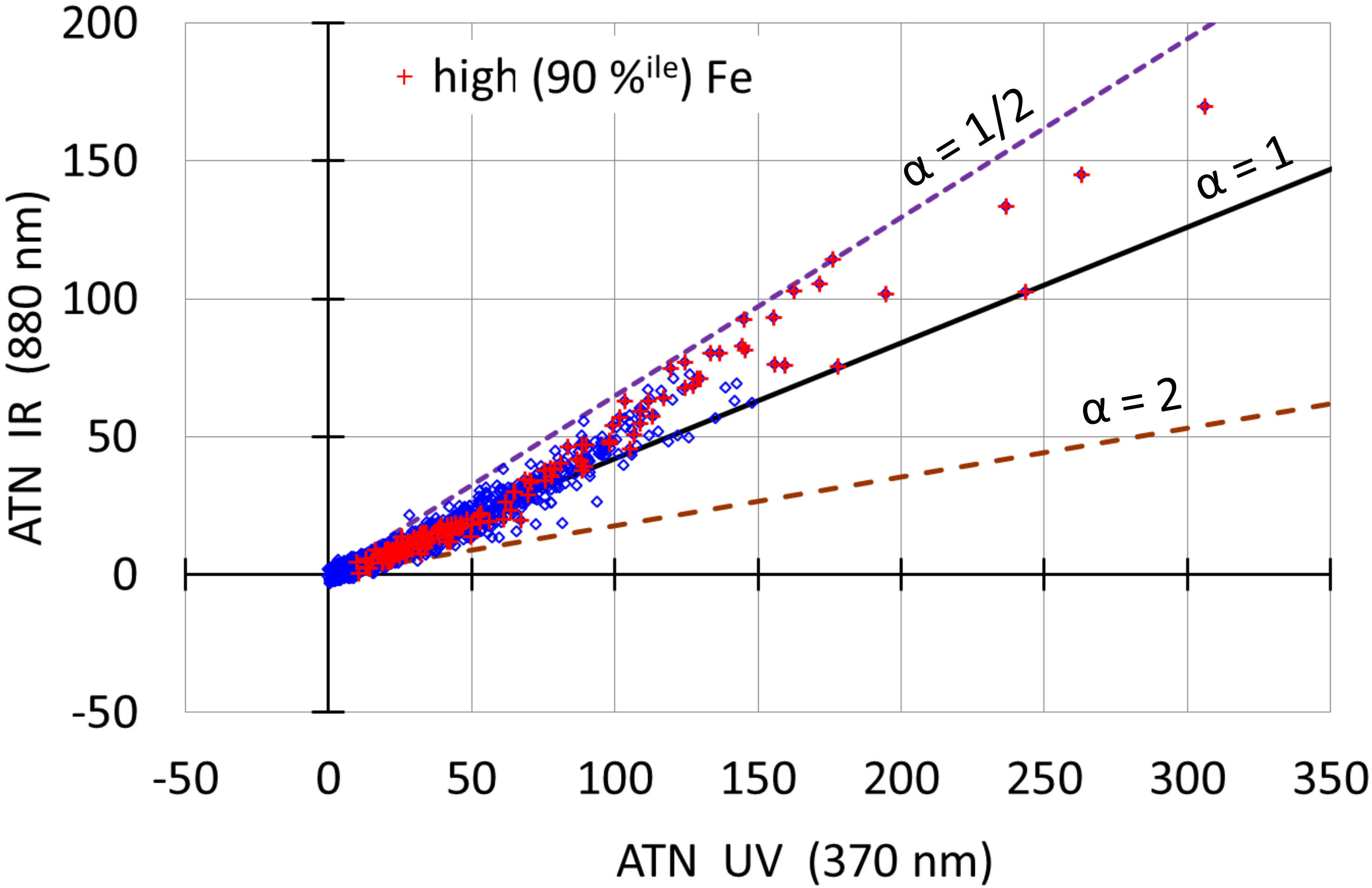
16 independent analyses of 6 CSN samples

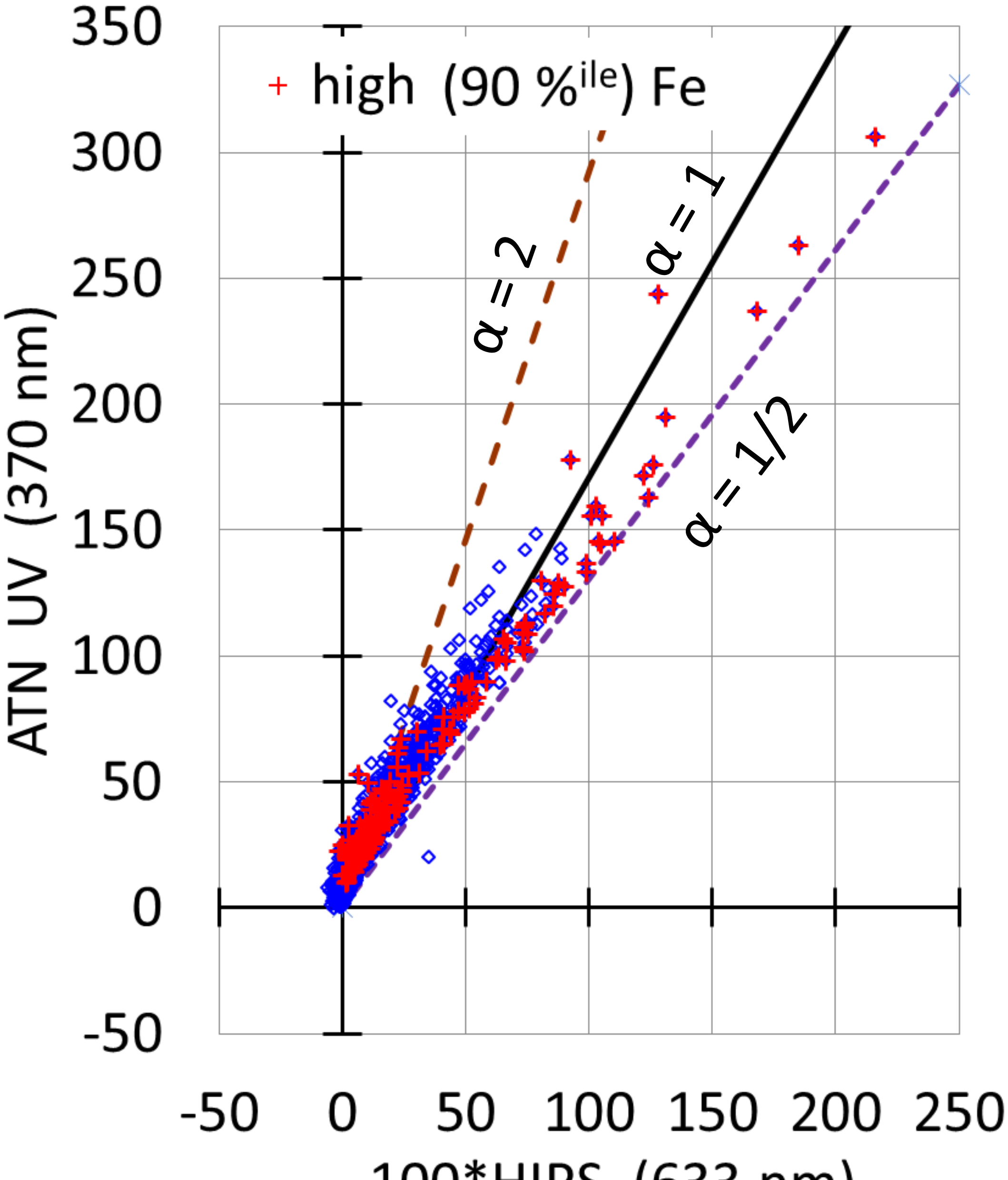


IMPROVE samples, March 2016 (n = 1632)



IMPROVE, March 2016 (n = 1632)





IMPROVE samples, March 2016 (n = 1632)