Carbonaceous aerosols, dust, and the absorption Angstrom exponent

Greg Schuster, NASA LaRC

Acknowledgements
This work was supported by NASA's Science Mission Directorate, Earth Science Division, Glory Science Team. We appreciate the efforts of the AERONET and PHOTONS (Service d'Observation from LOA/USTL/ CNRS) principal investigators and the entire AERONET/PHOTONS teams.

Outline

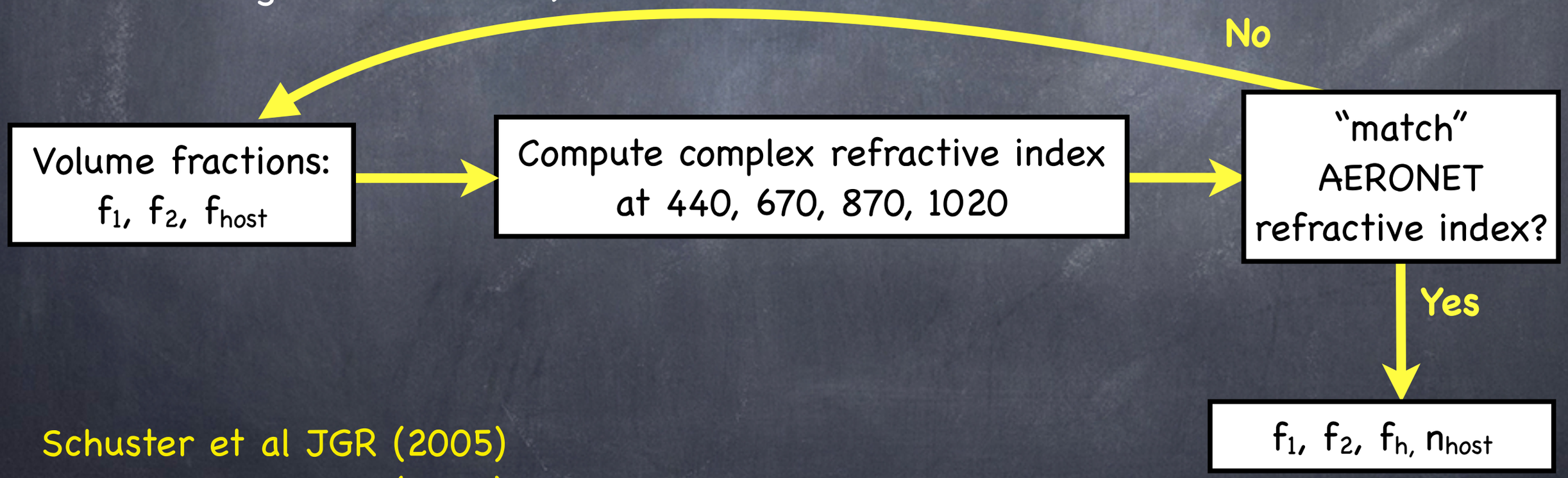
- Description of retrieval from AERONET Lev 2.0 almucantar data
- Absorption Angstrom Exponent (AAE)
- Usage comments about AERONET products

Motivation

- There has been recent interest in separating the absorption contributions of dust, black carbon and organic carbon (Bond 2013, Chung 2012, Bahadur 2012).

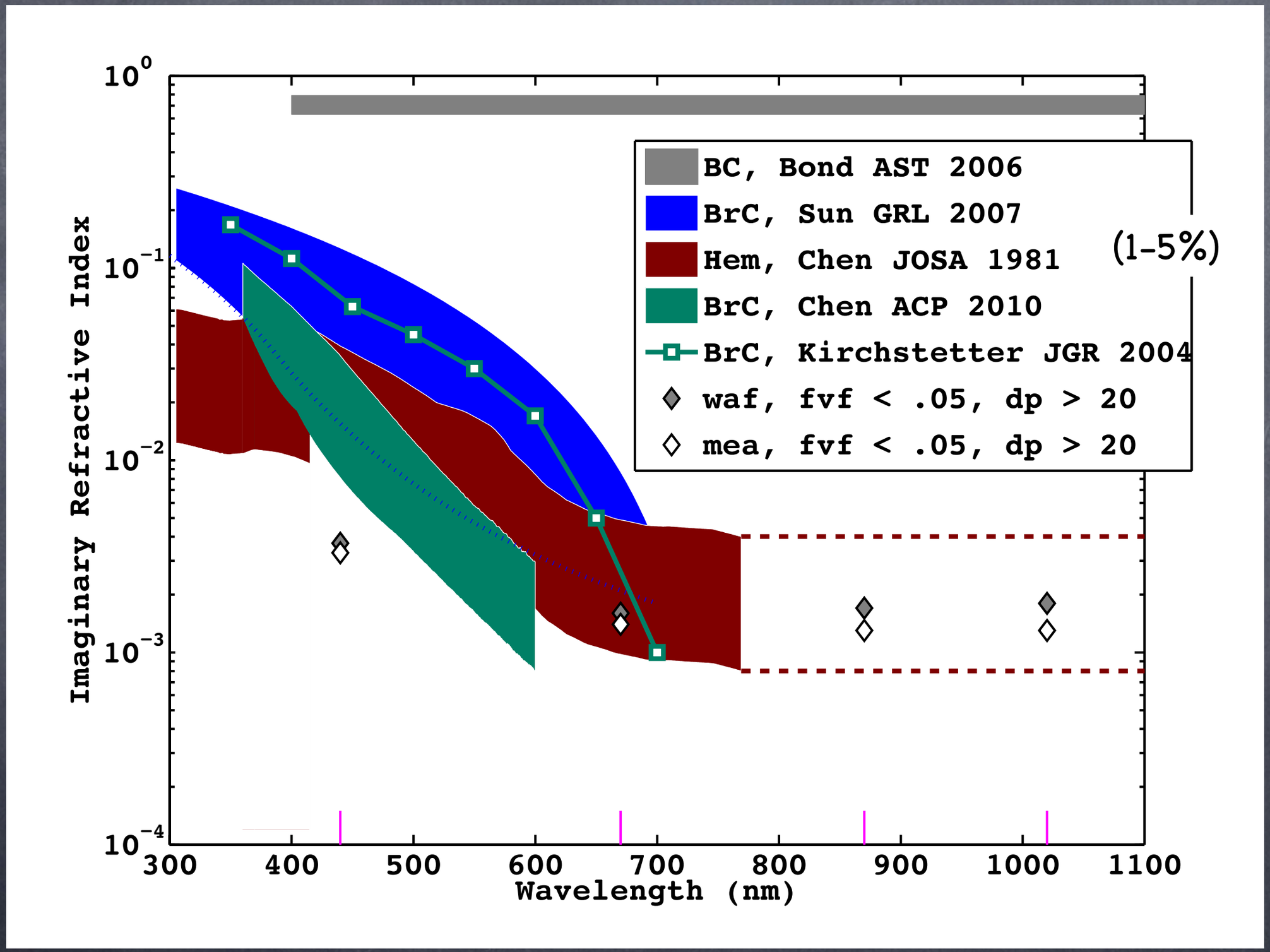
- AERONET provides imaginary refractive index (i.e., absorption) at 4 wavelengths (440, 675, 870, 1020 nm) and the aerosol volume.

- These refractive indices can be used to infer the volume fraction of one spectrally flat absorbing species and one colored species in a non-absorbing host (i.e., BC and OC for carbonaceous aerosols, hematite and goethite for dust).

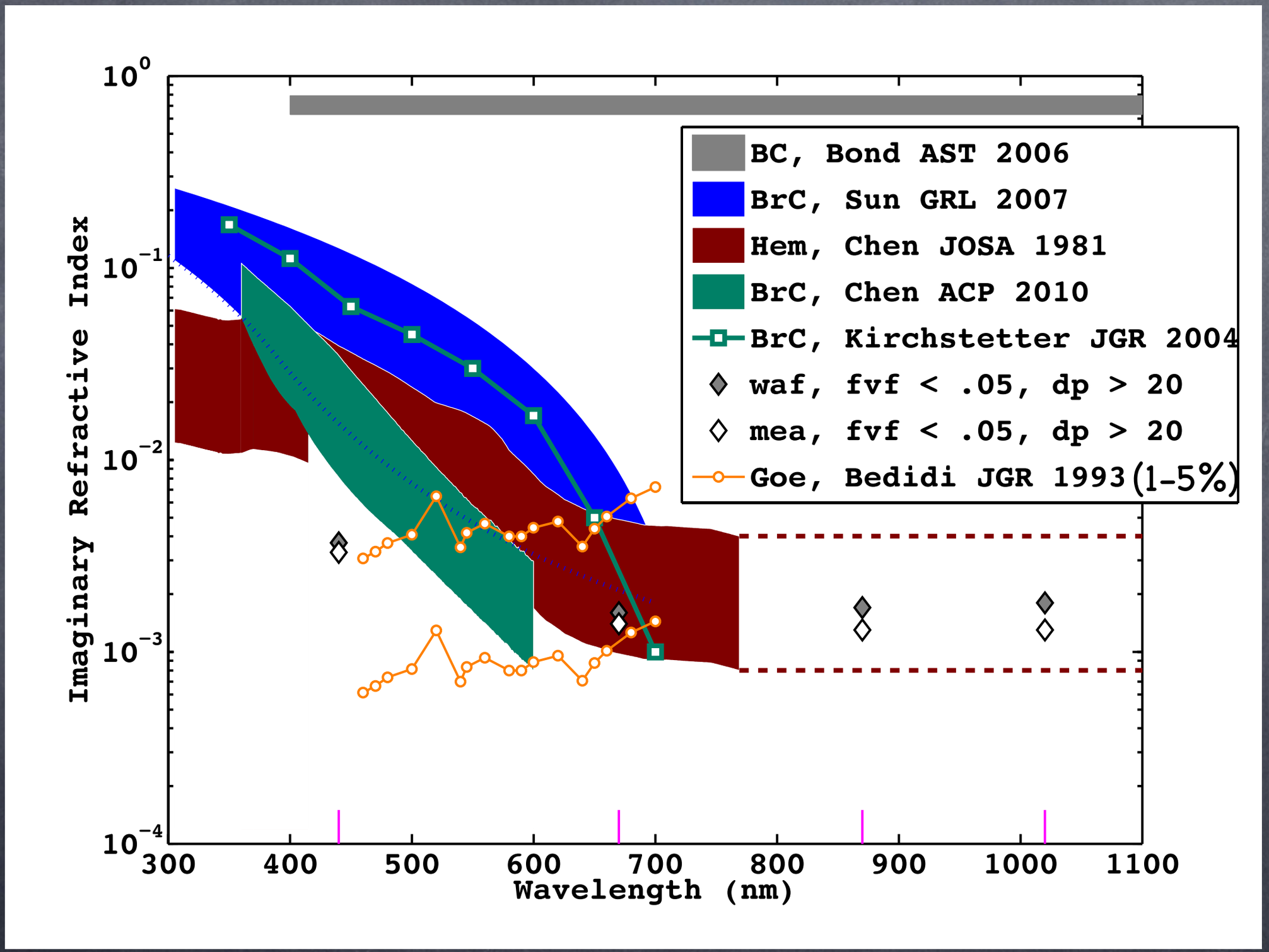


Schuster et al JGR (2005)
Schuster et al GRL (2009)

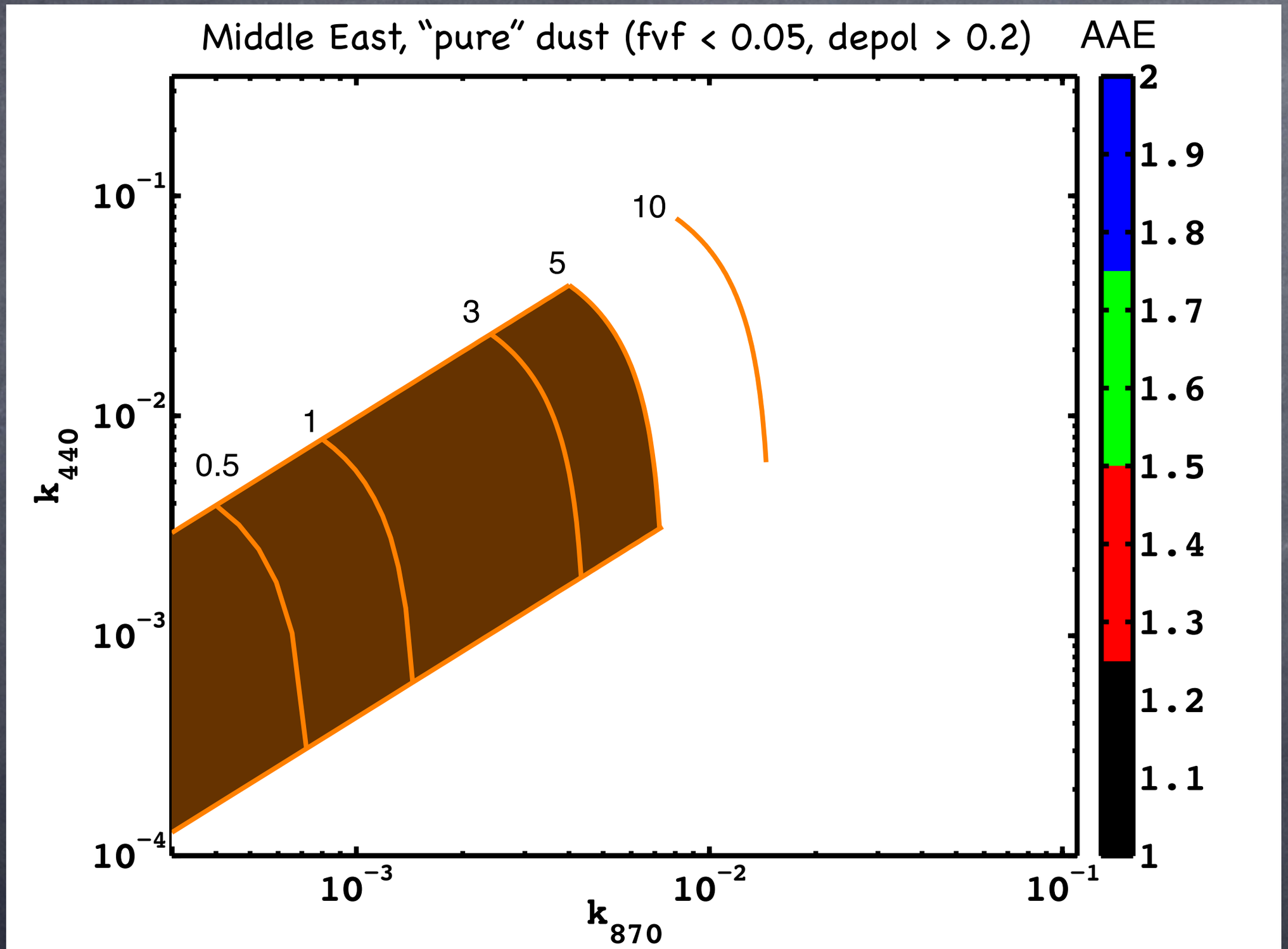
Imaginary refractive indices of the four common absorbing aerosol species



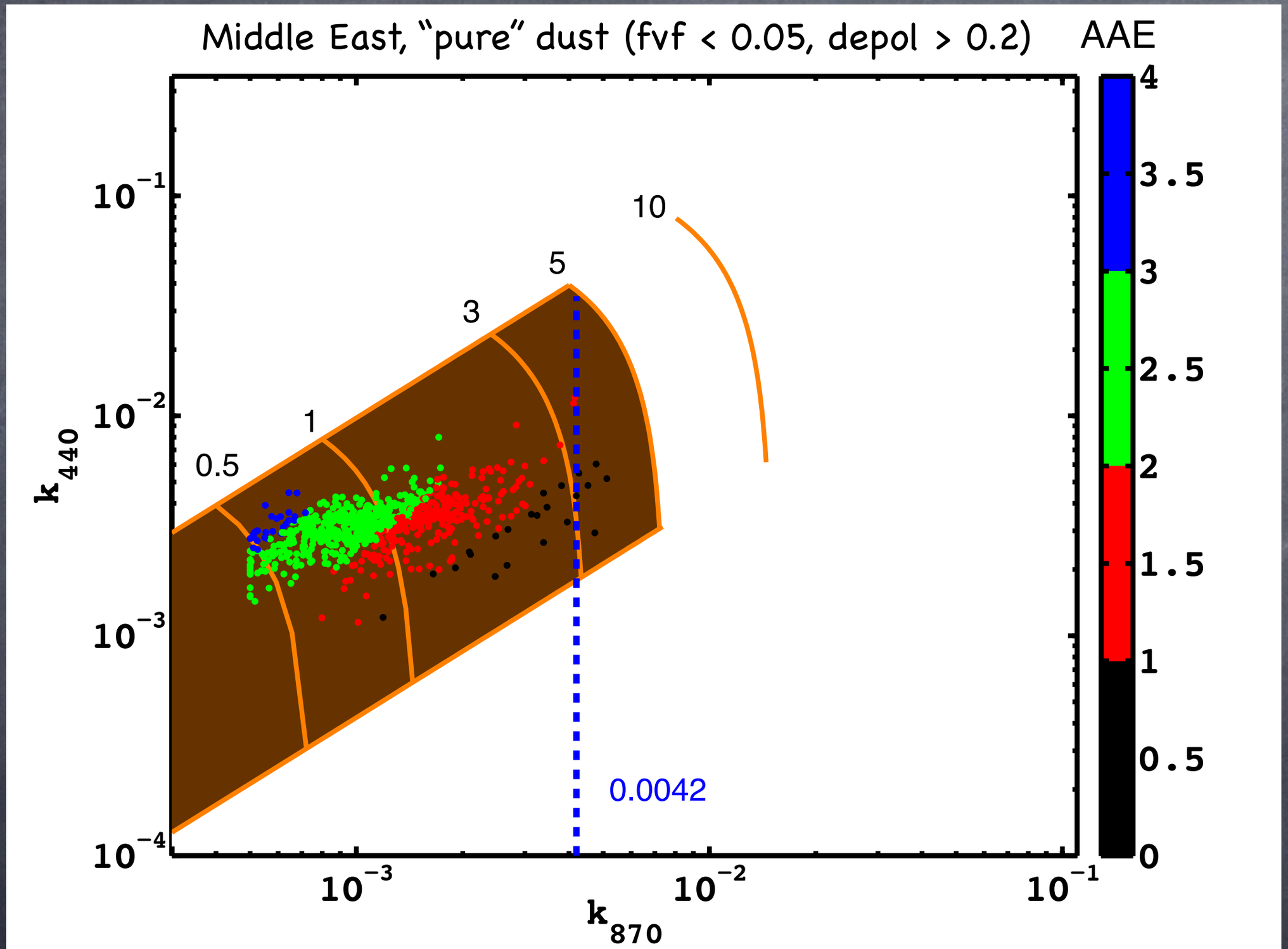
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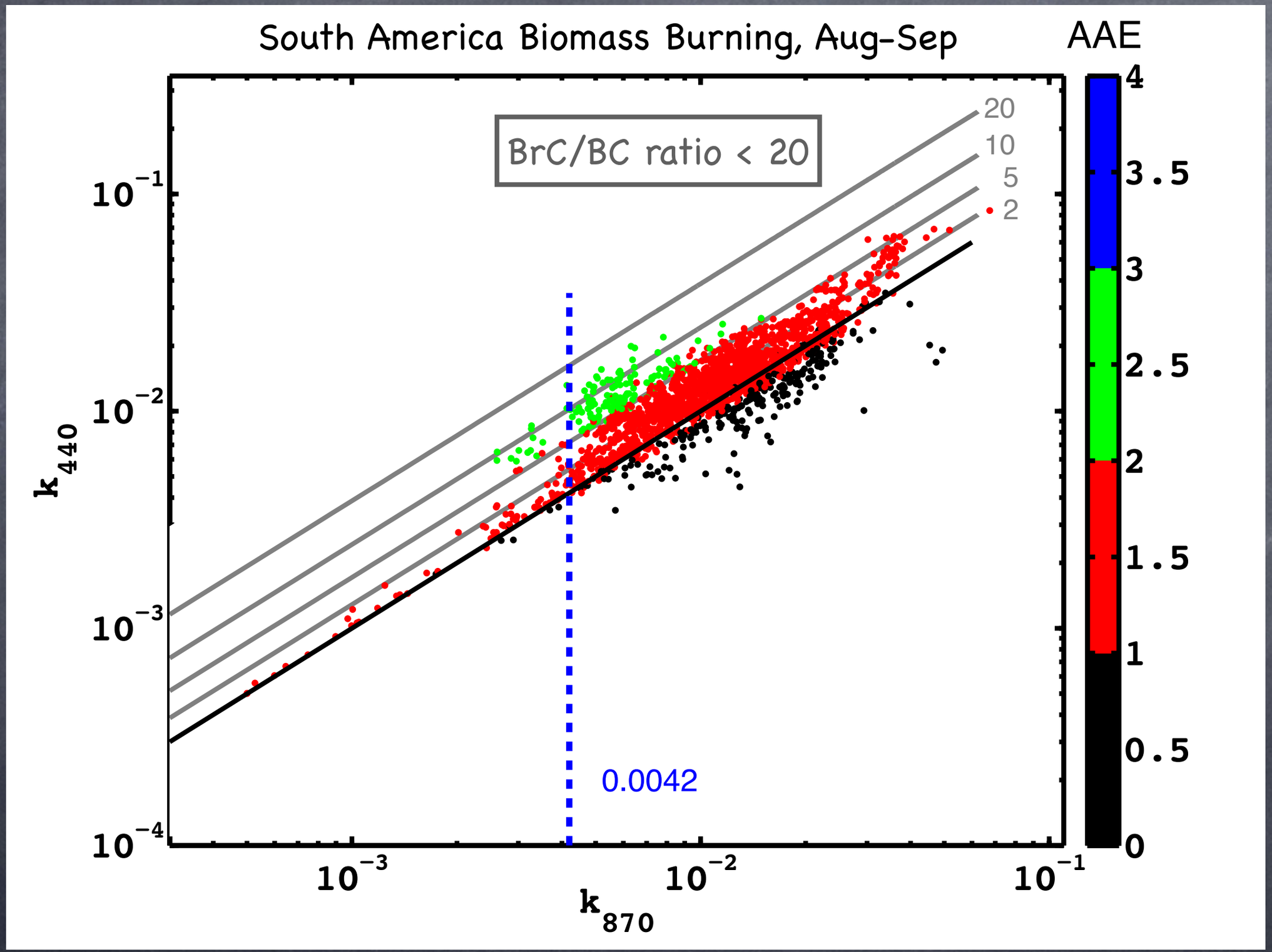
Hematite-goethite mixtures in imaginary index space



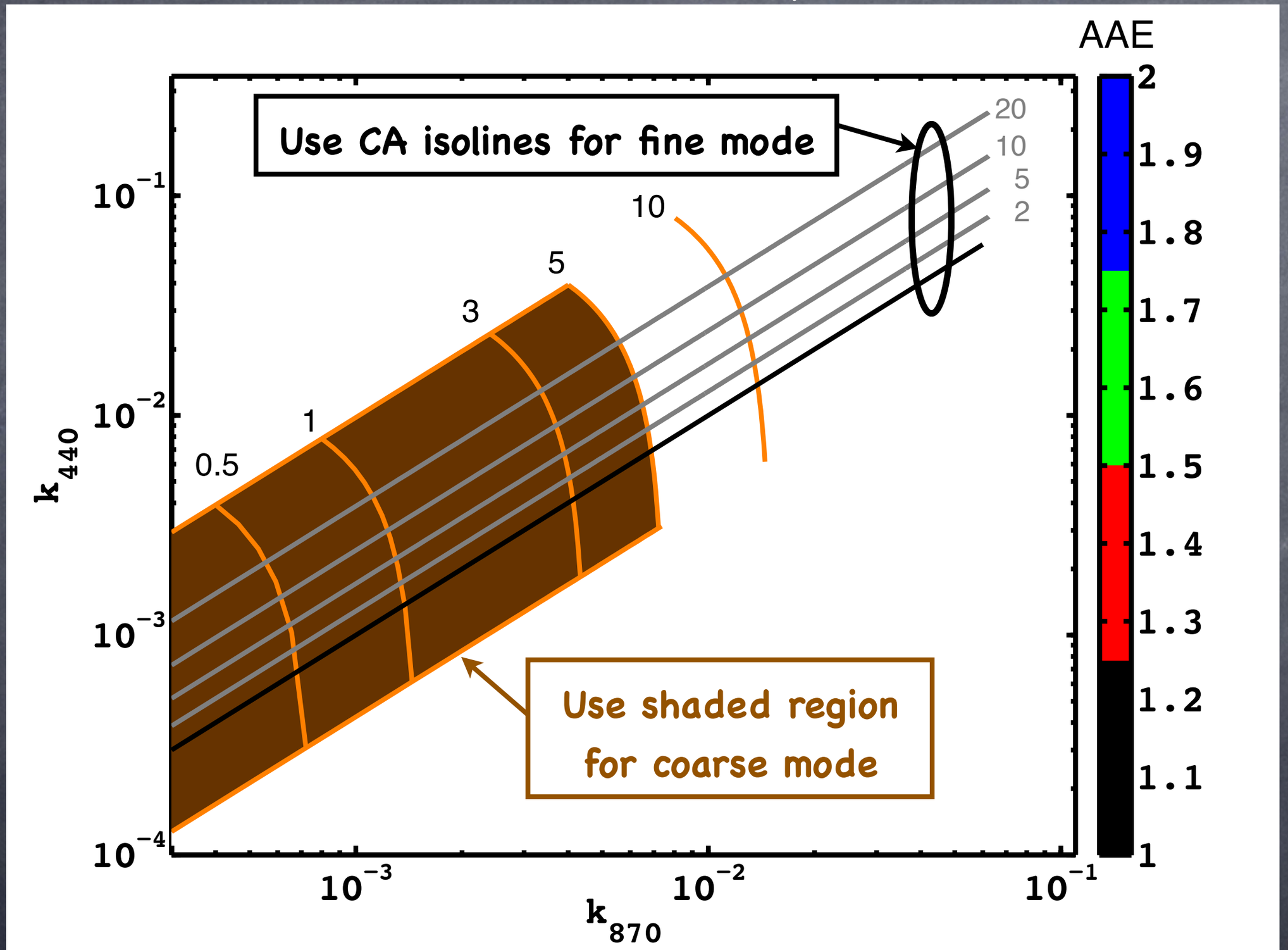
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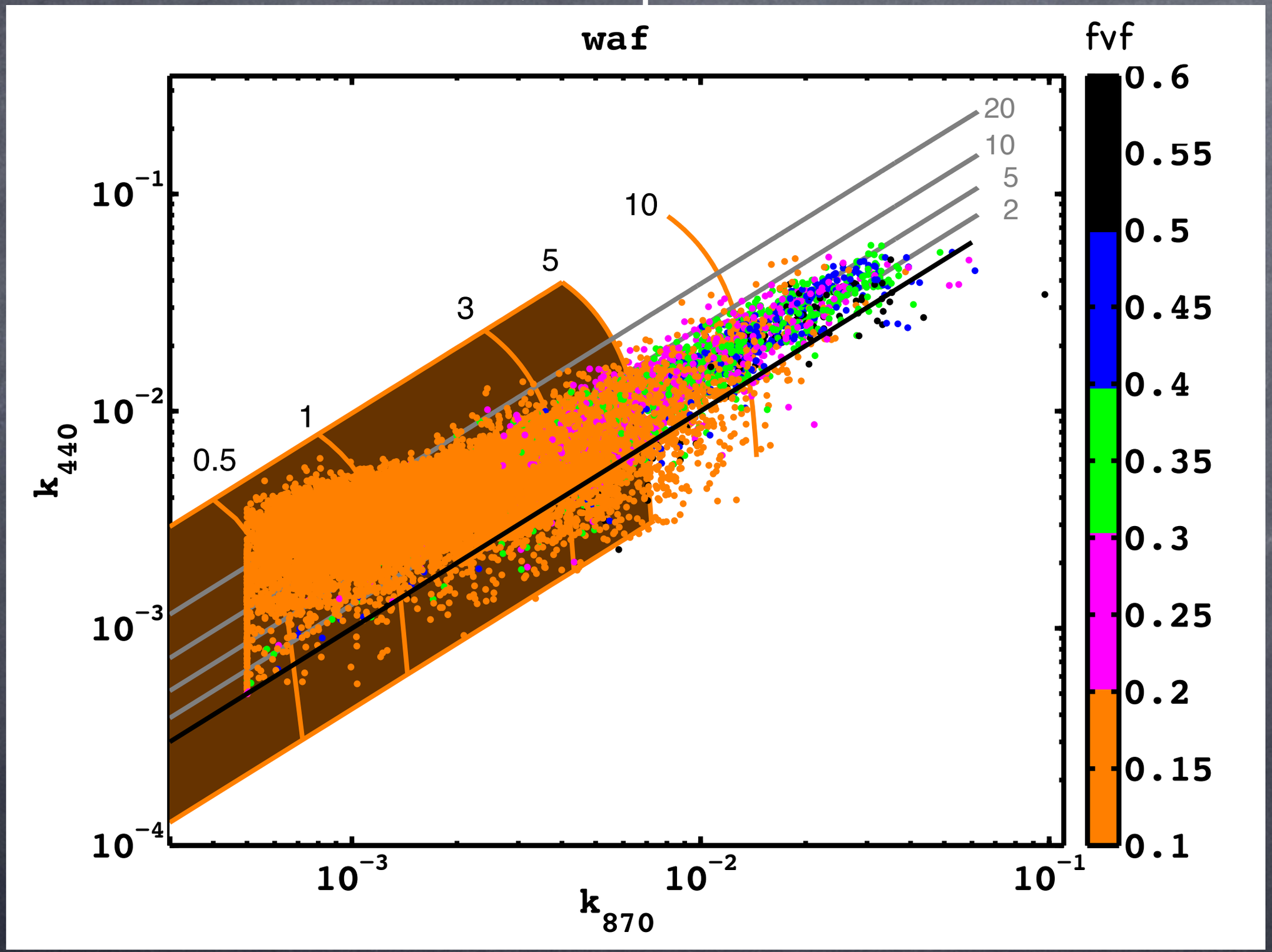
BrC-BC mixtures in imaginary index space



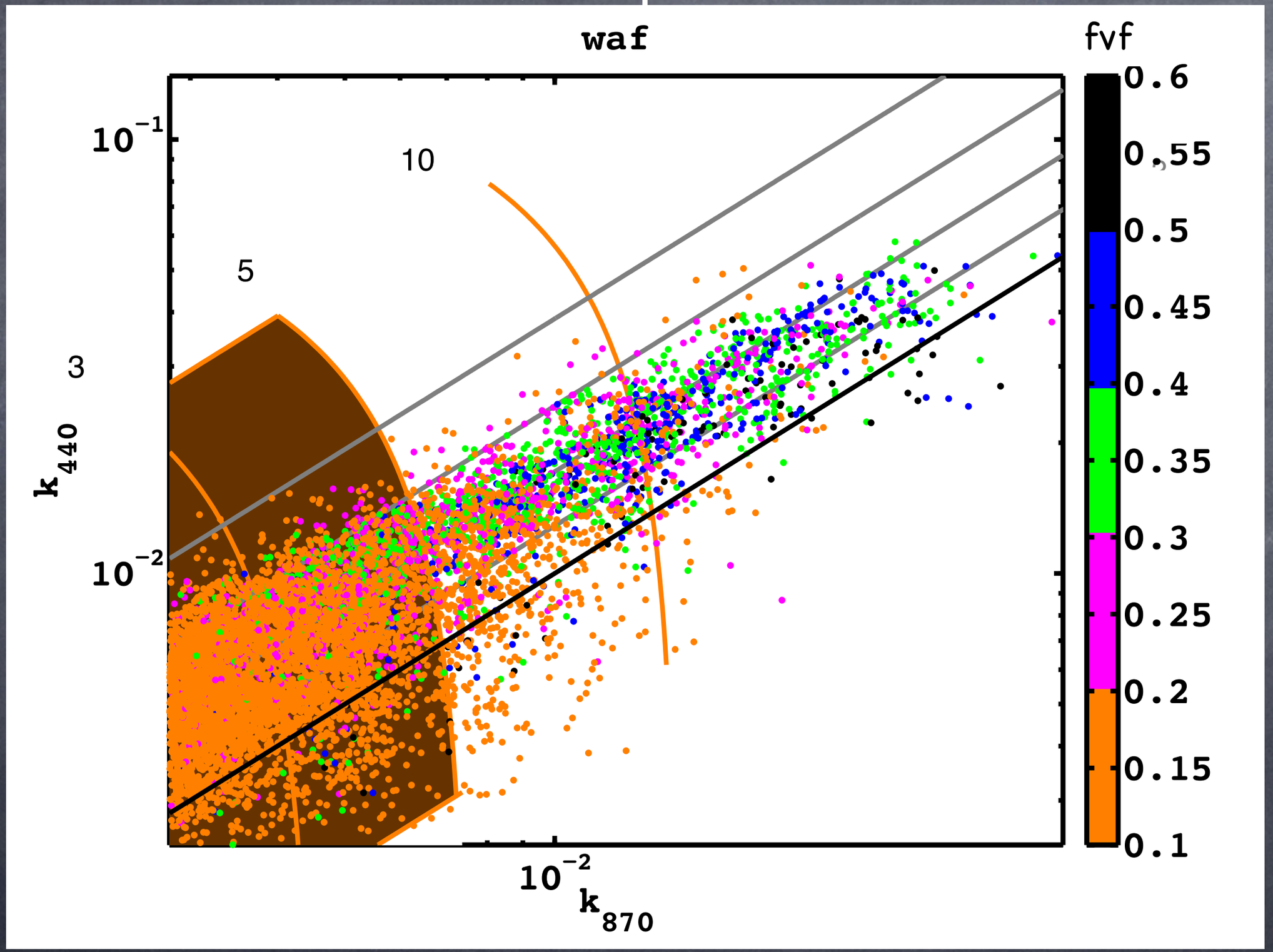
First thought: Assume all fine mode absorption is caused by BC, and all coarse mode absorption is caused by dust.



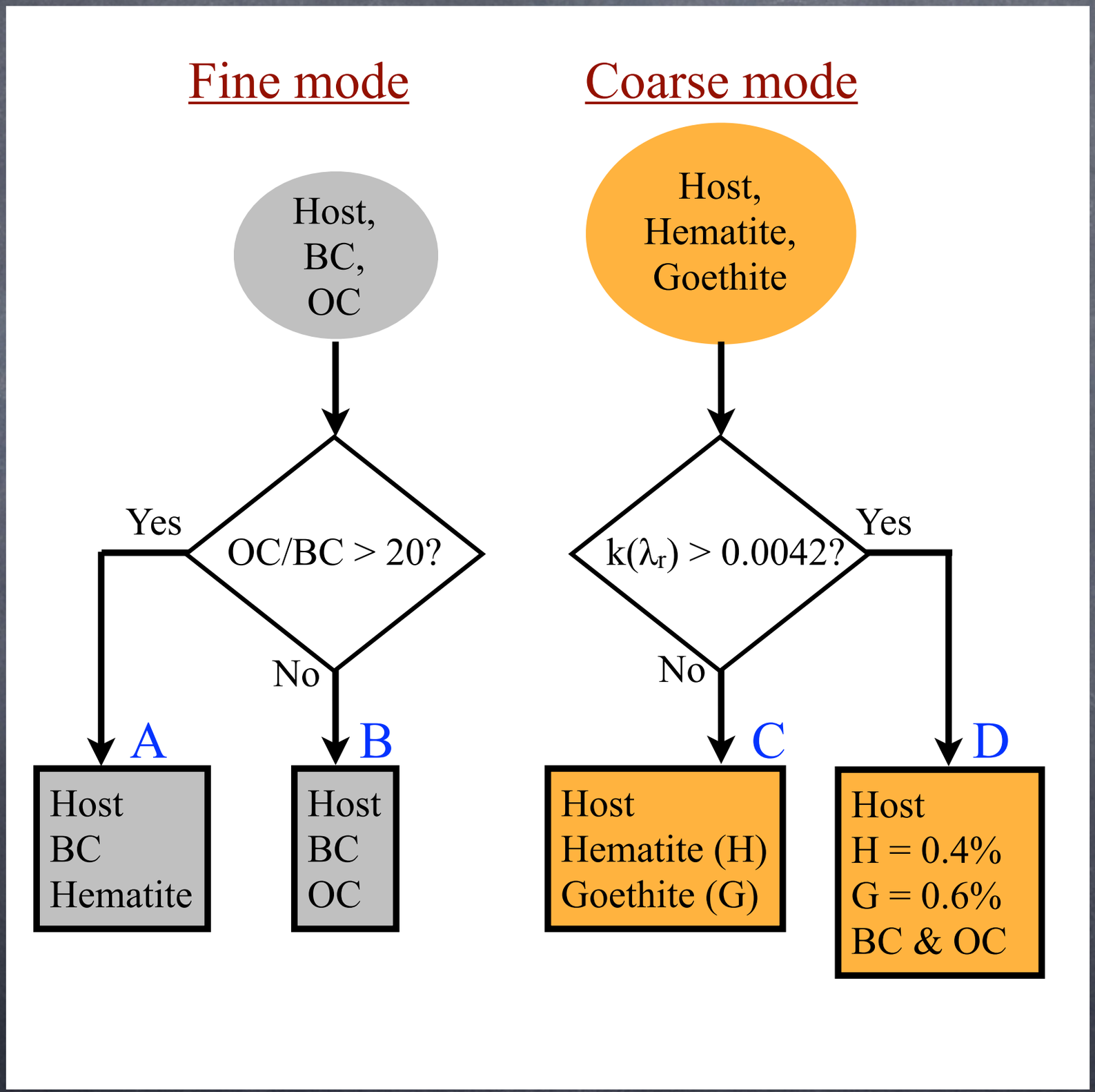
Problem: Refractive indices fall outside of known range for dust in West Africa, despite coarse-mode dominance



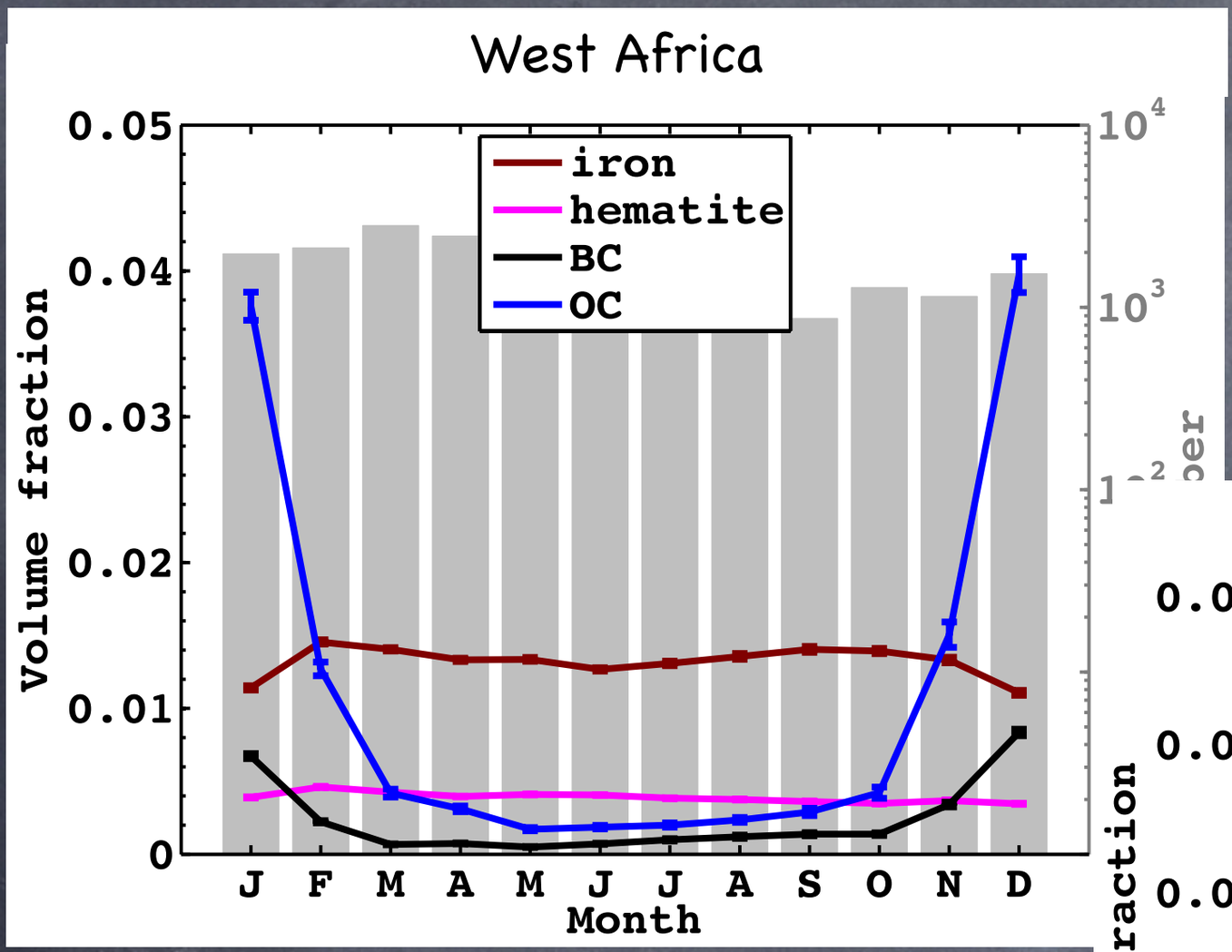
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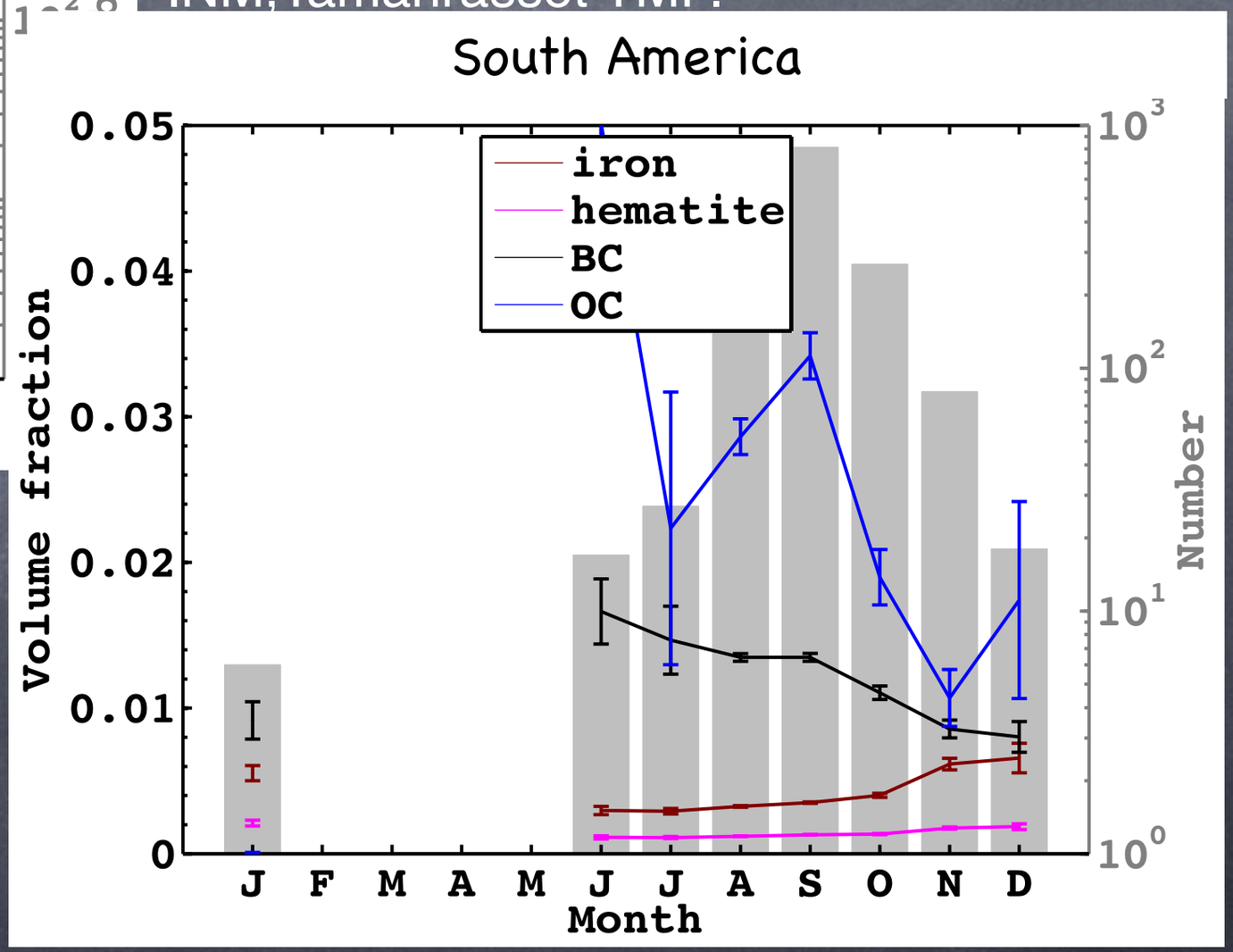
Next thought: Use thresholds determined from imaginary index space to constrain absorbing species concentrations



Volume fraction

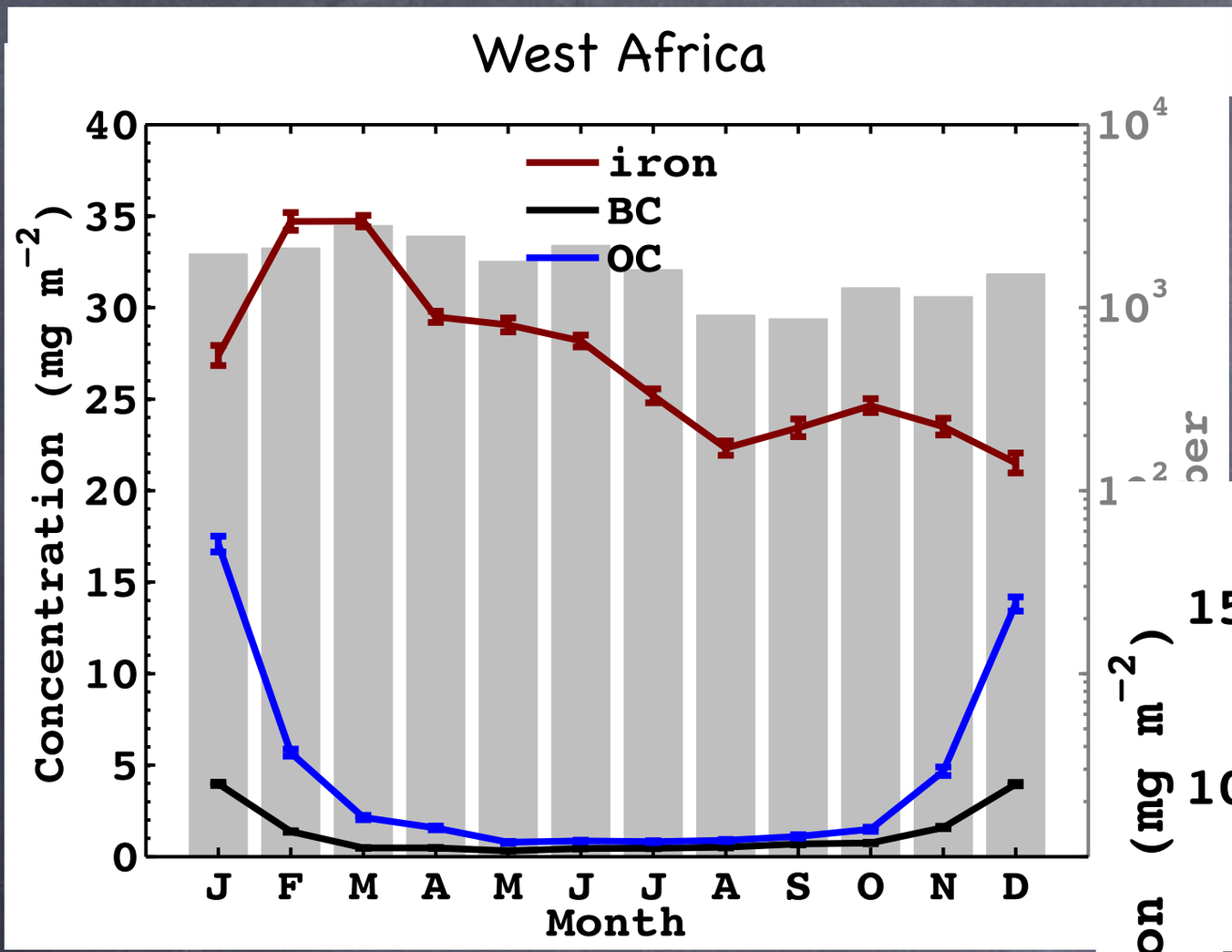


West Africa (waf):
Agoufou, Banizoumbou, IER Cinzana, DMN Maine Soroa,Ouagadougou, Djougou, Saada, Capo Verde, Dahkla, Dakar,Ilorin, Quarzazate, Santa Cruz Tenerife, Tamanrasset INM,Tamanrasset TMP.

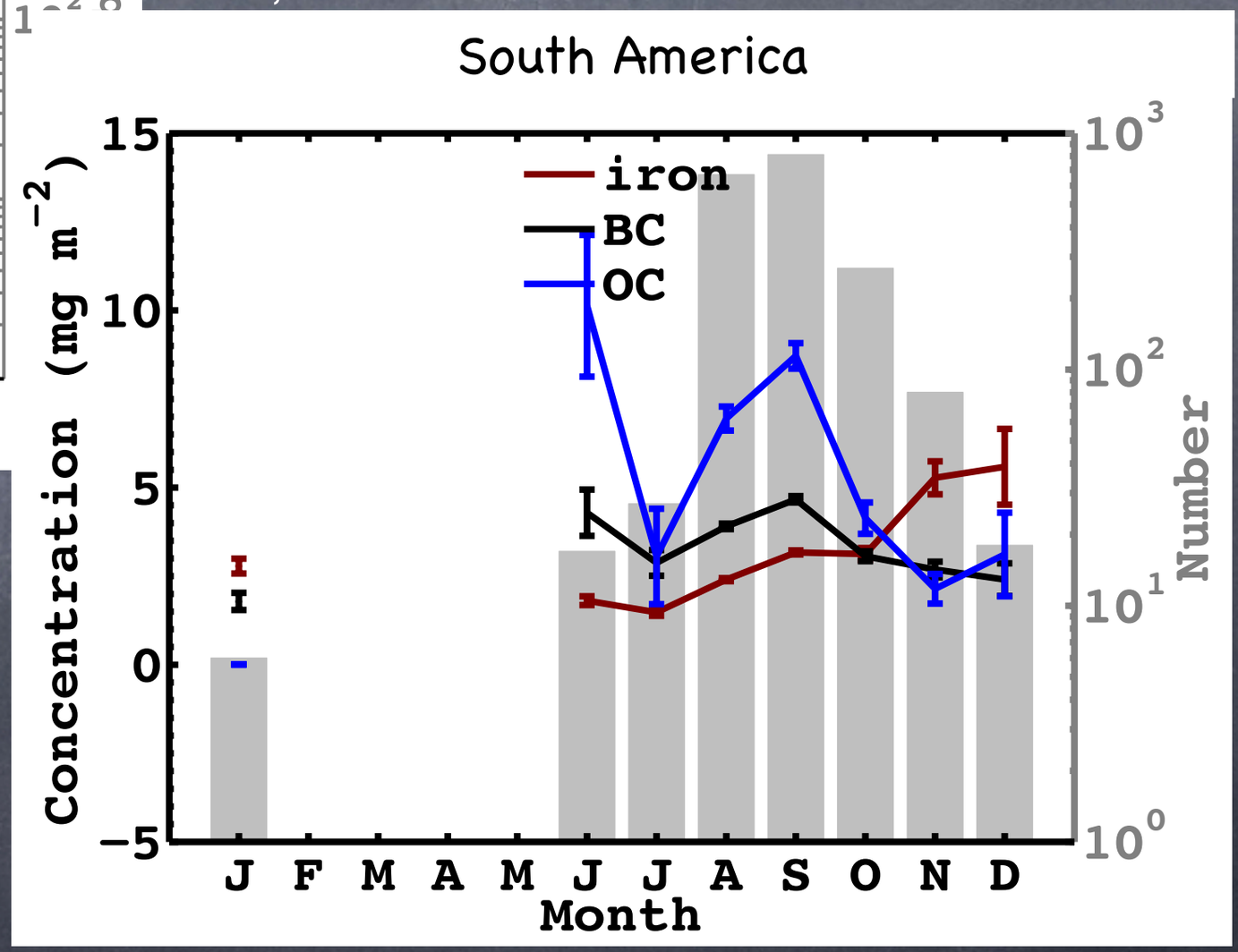


South America (sam):
Alta Floresta, Cuiaba, CUIABA-MIRANDA, Abracos Hill, Balbina, Belterra, SANTA CRUZ.

Concentration



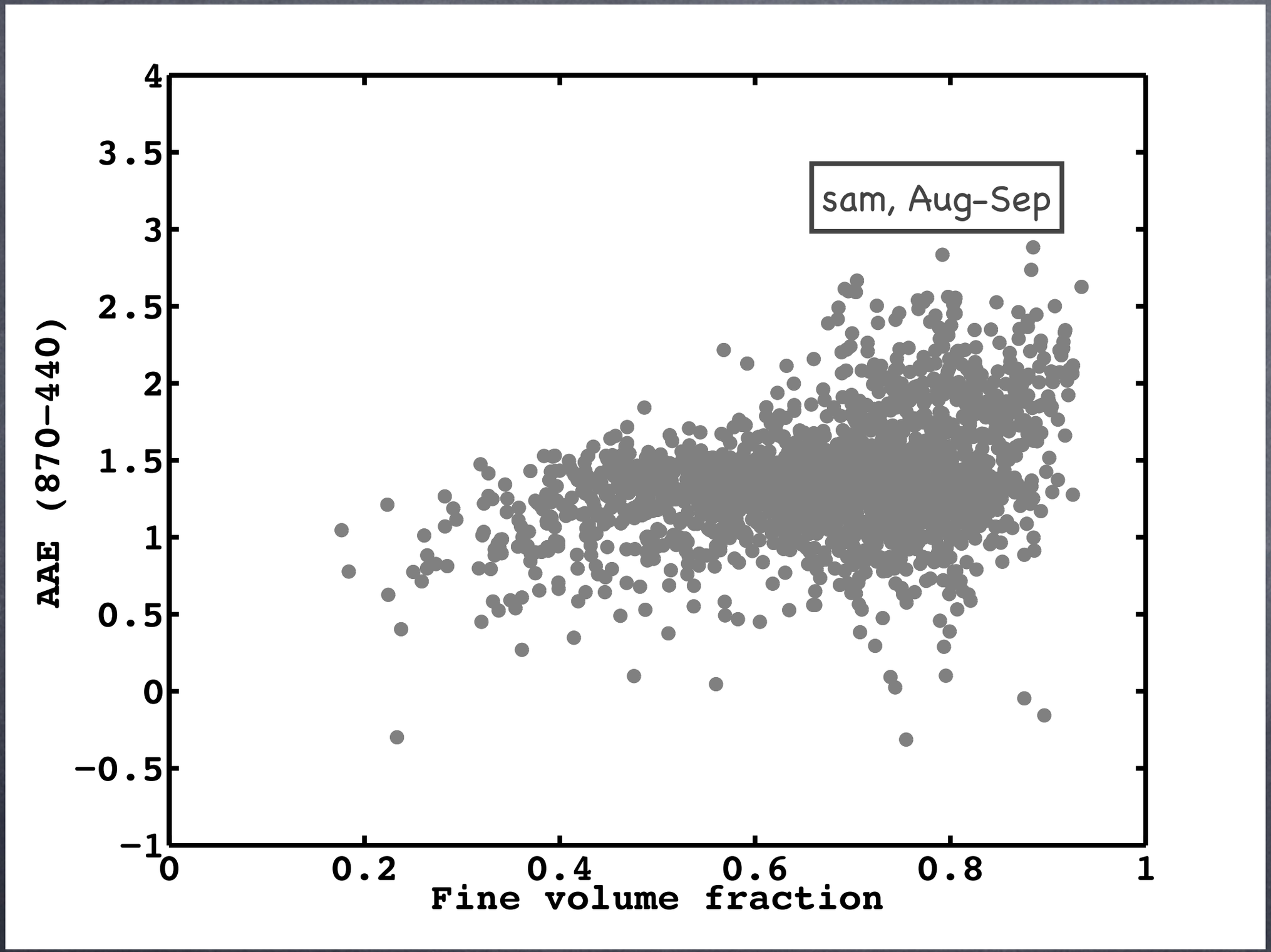
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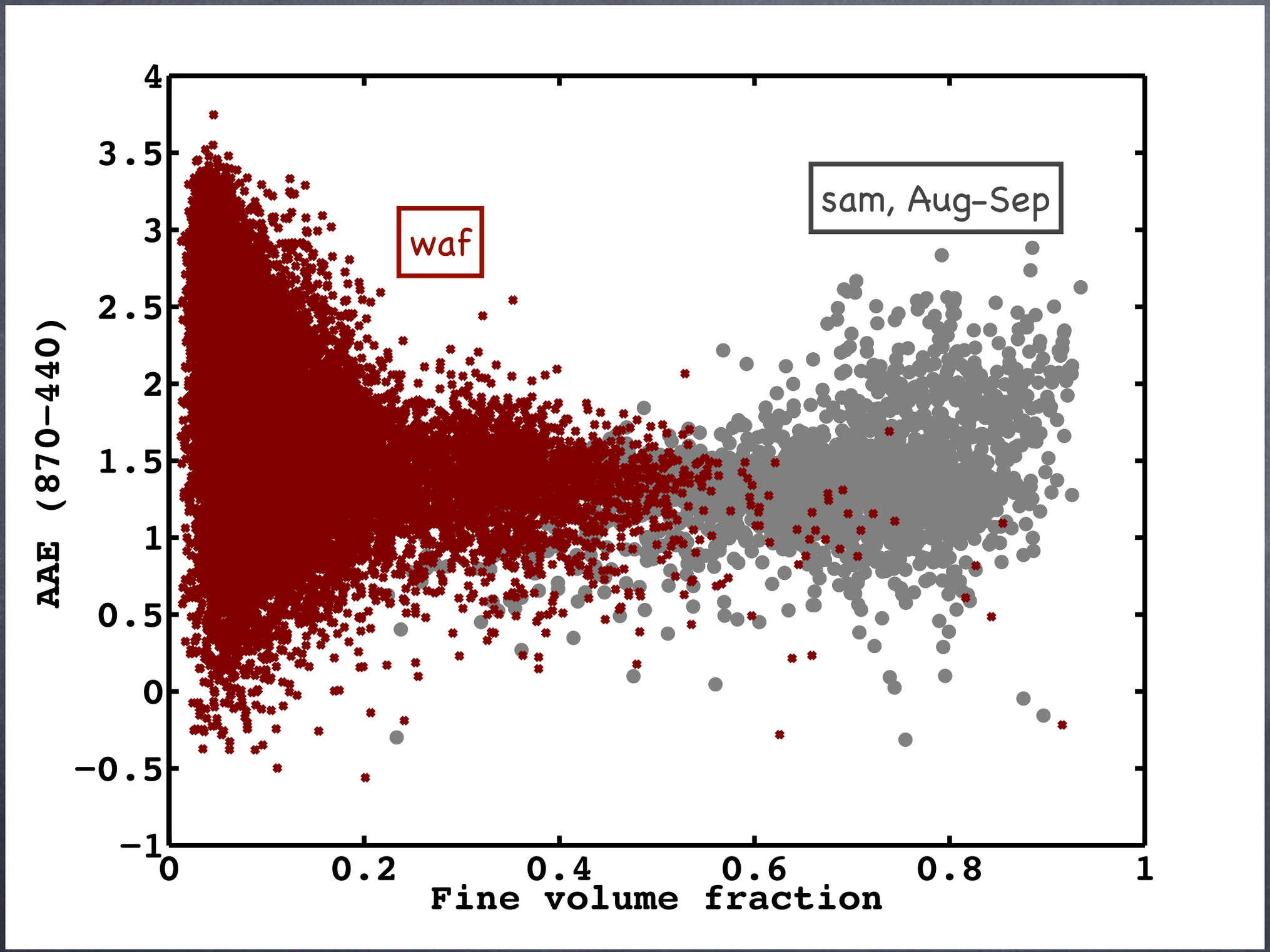
AAE Approach for separating aerosol absorption

(Arola ACP 2011, Chung PNAS 2012, Bahadur, PNAS 2012)



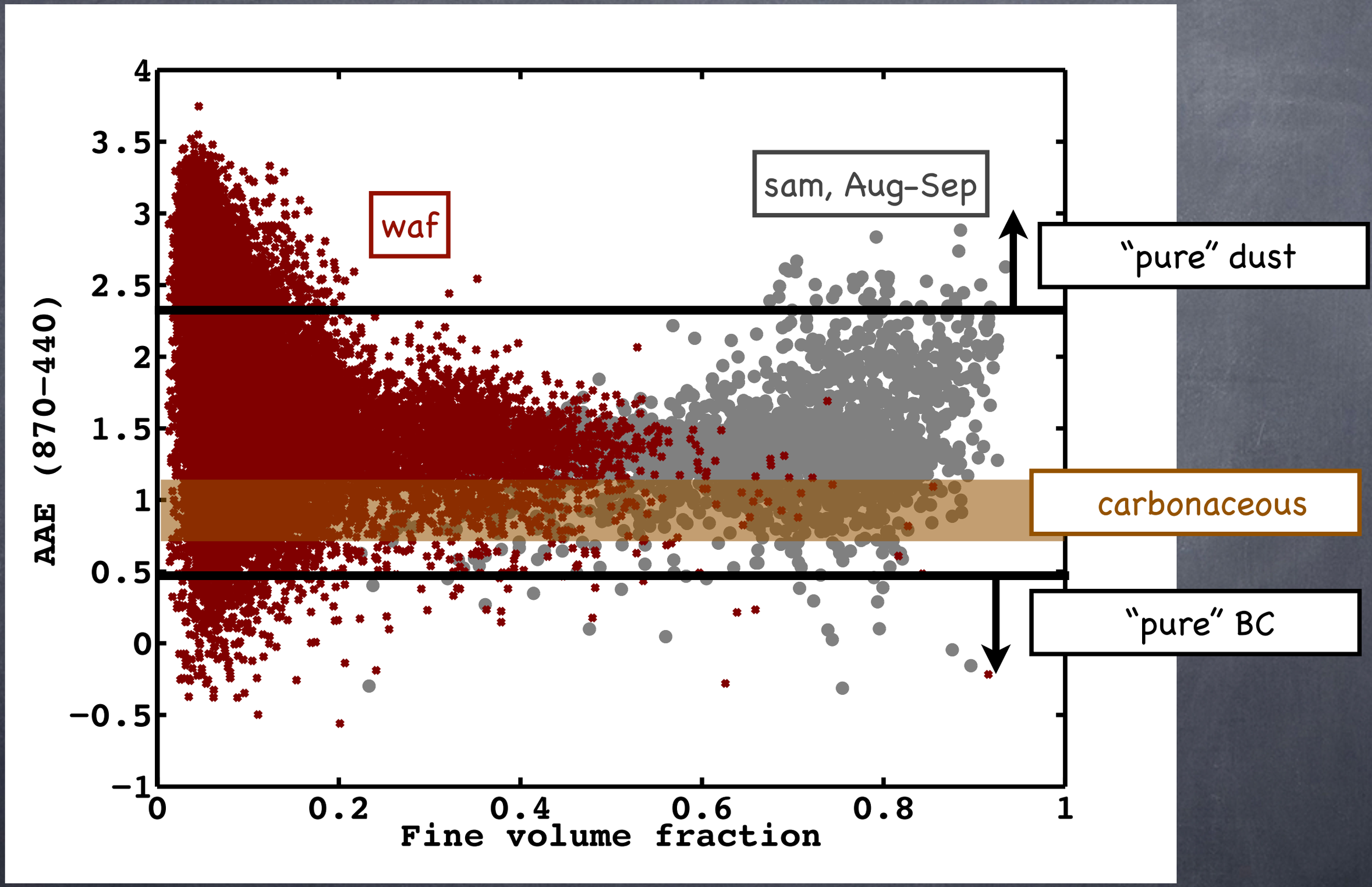
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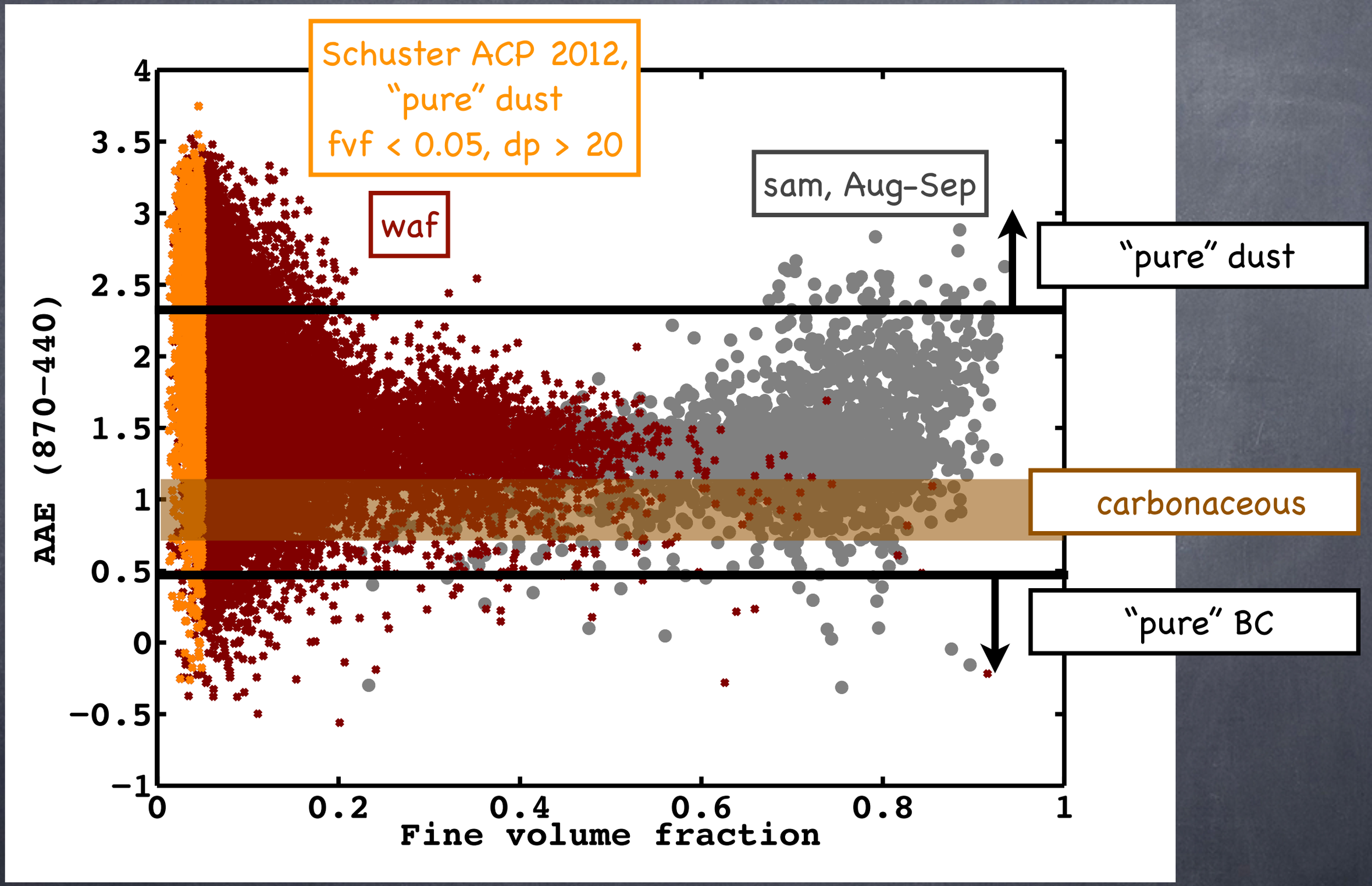
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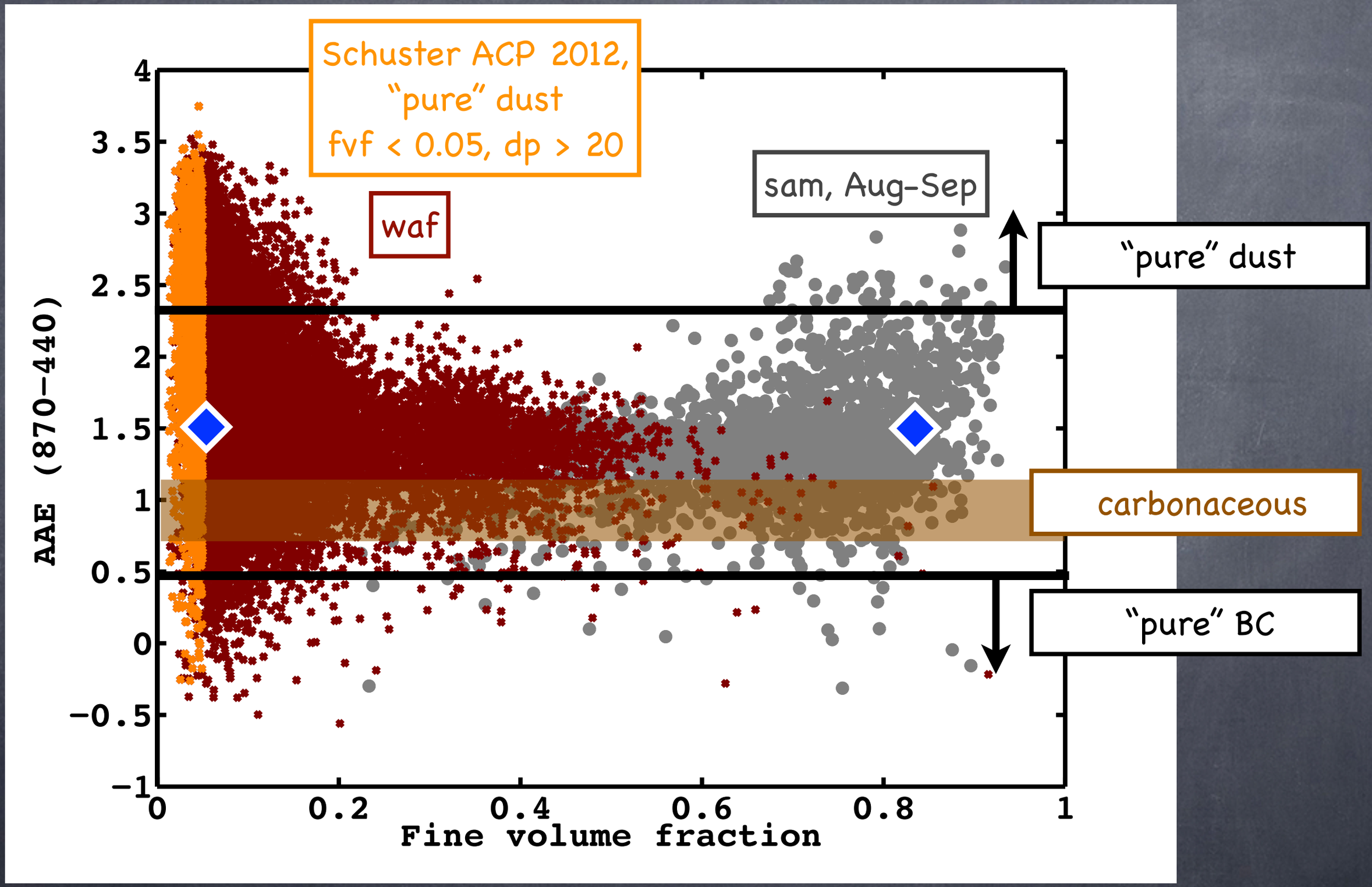
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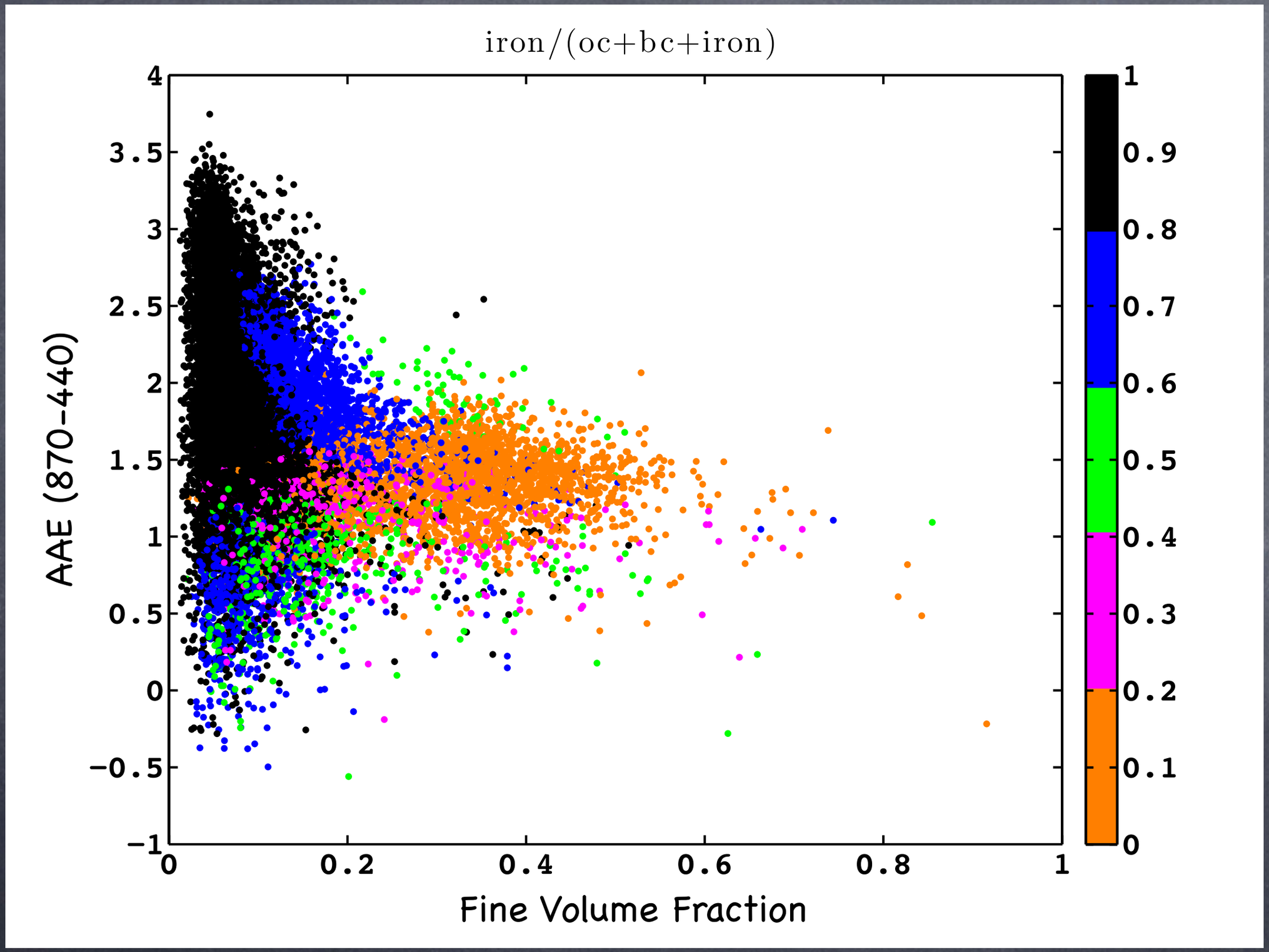


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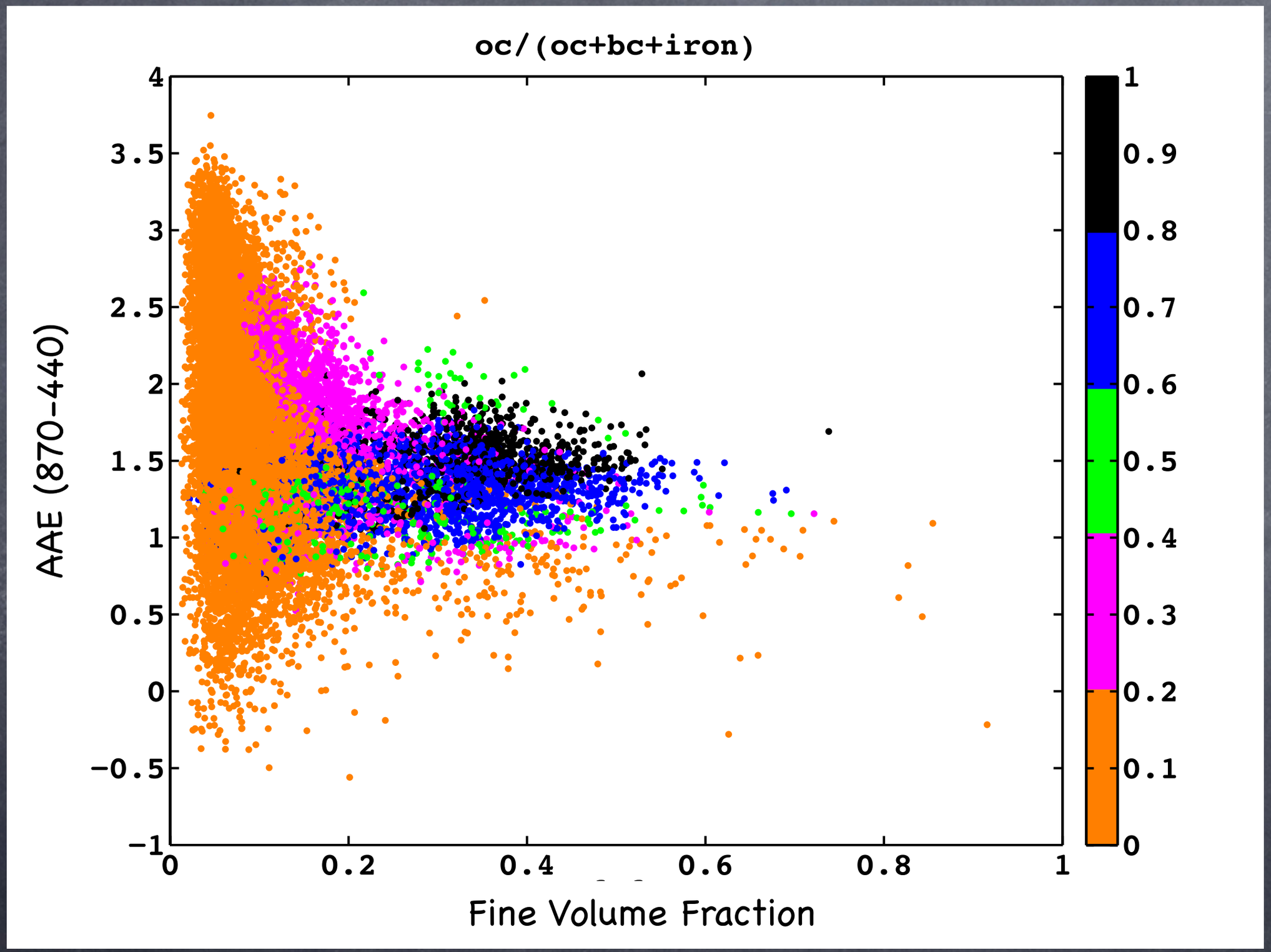
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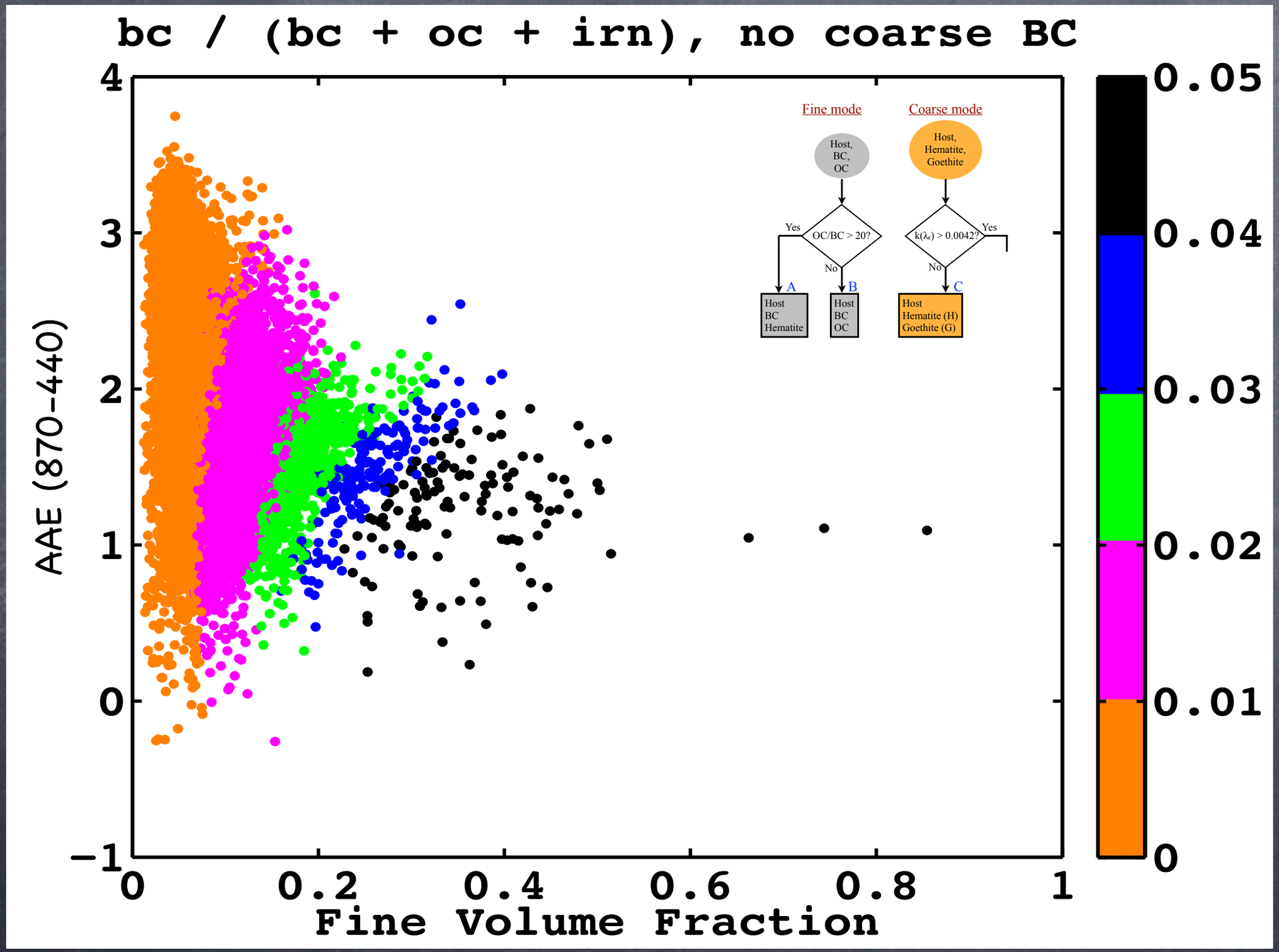
Iron fraction wrt all absorbers, W. Africa



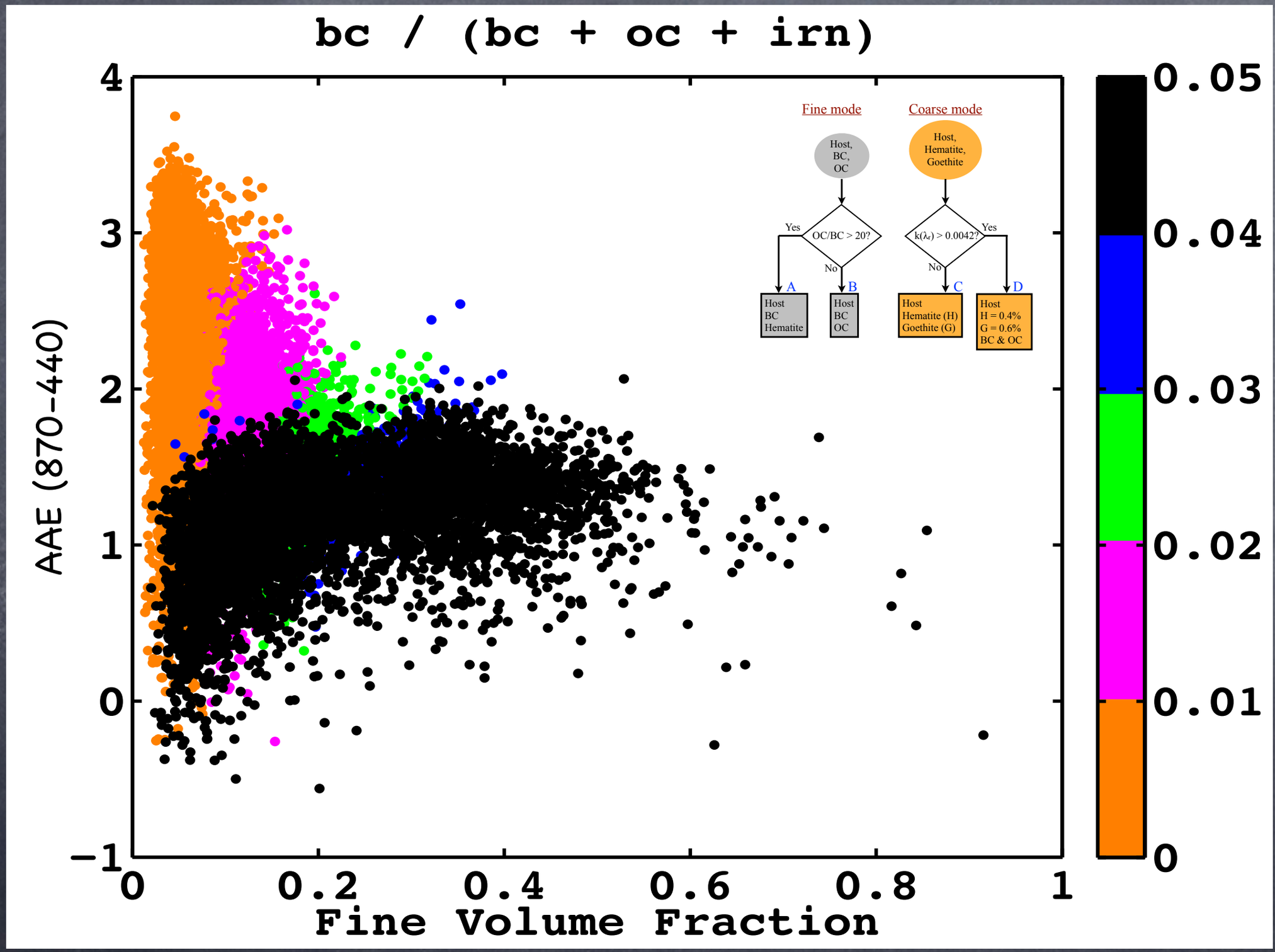
OC fraction wrt all absorbers, W. Africa



BC fraction wrt all absorbers, W. Africa



BC fraction wrt all absorbers, W. Africa



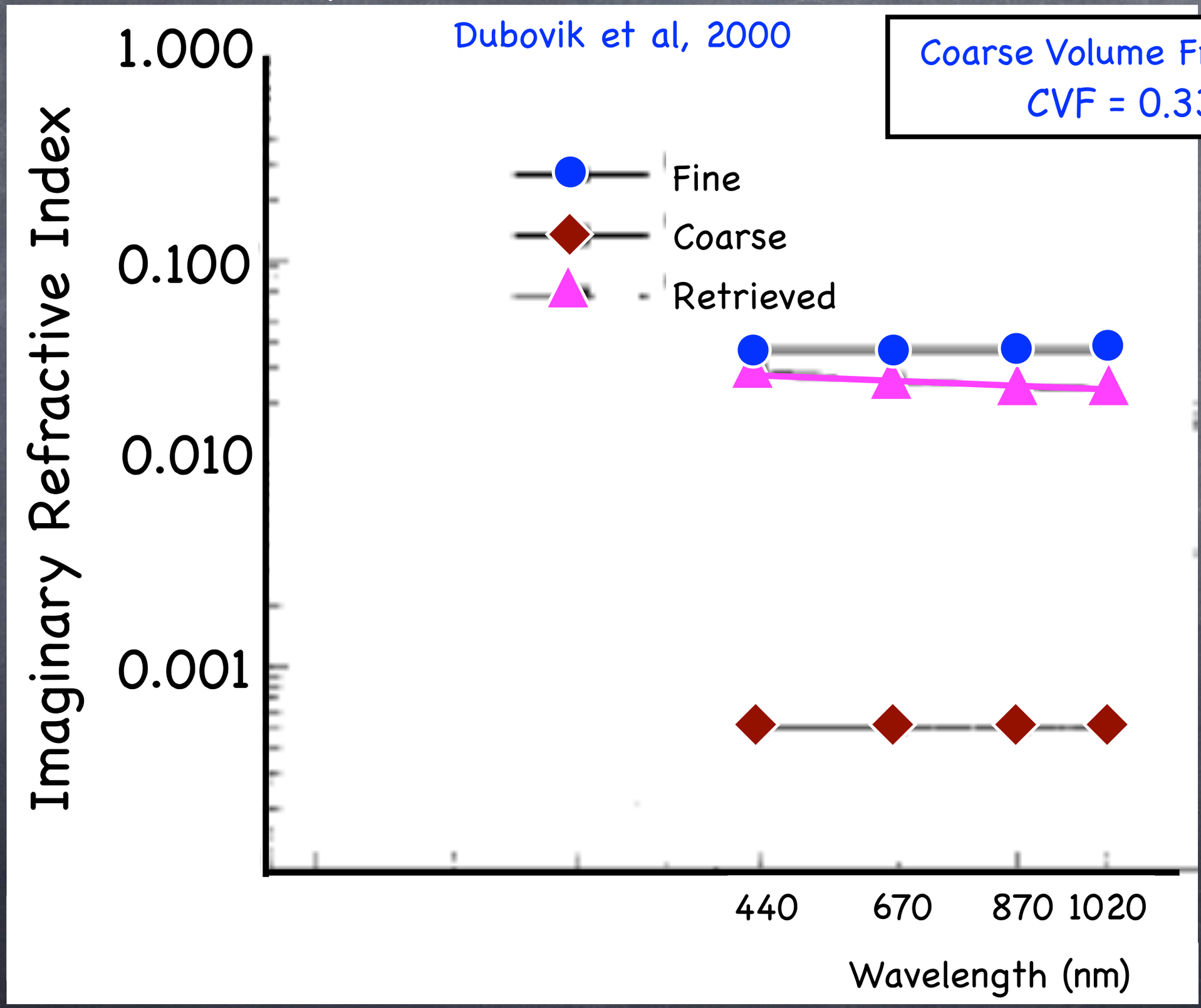
Some thoughts on the use of AERONET retrievals

- AERONET's "coincident" AOD is a separate product from "all" AOD that modelers should check before using the other advanced products. The coincident AOD is always > 0.4 at 440 nm.

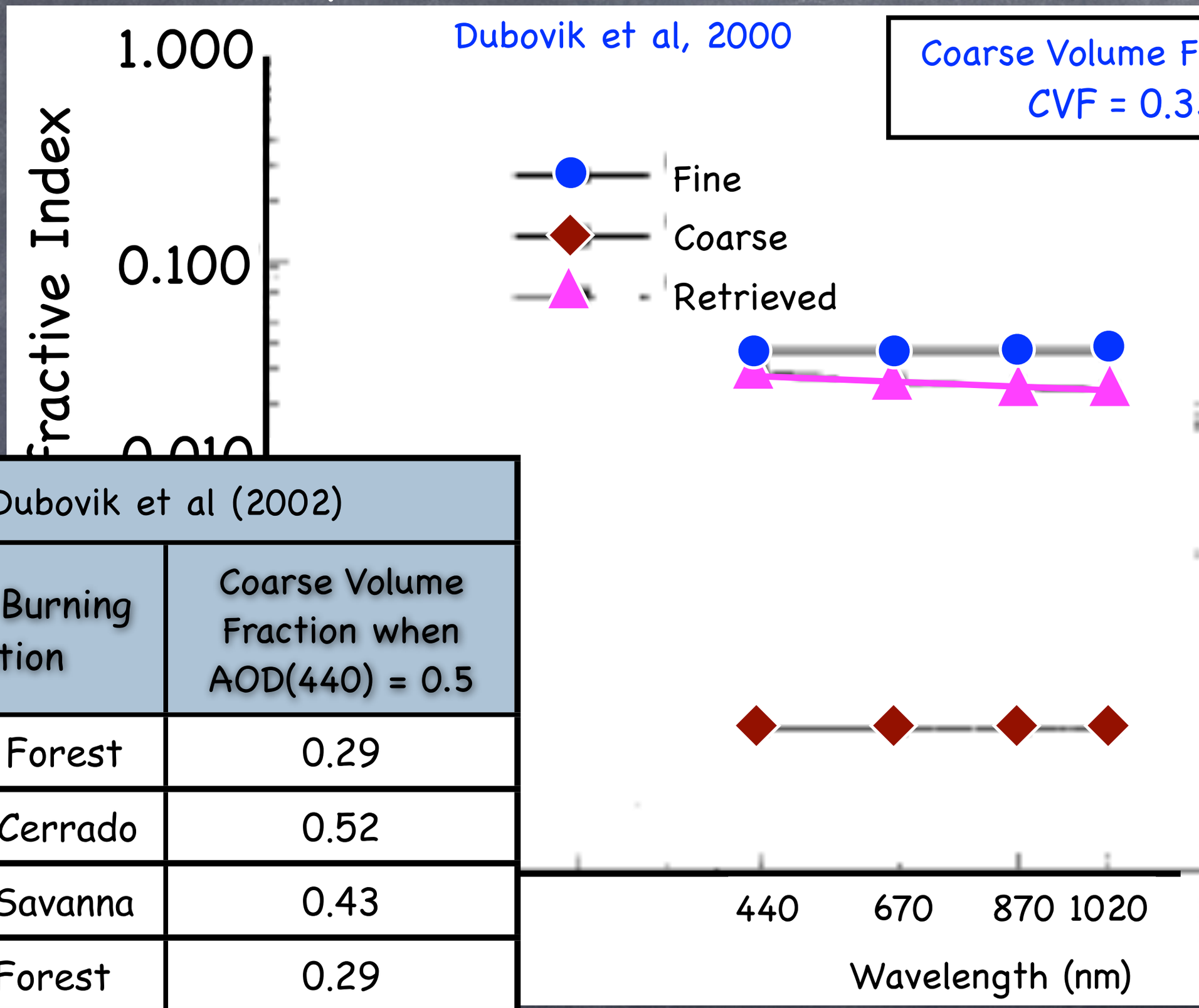
- How to handle AAOD at low AOD... Robustness of Lev 1.5 data for climatologies is still questionable (come see my poster!). Modelers should consider subsampling results with AOD > 0.4 to validate/constrain with advanced Lev 2 AERONET products.

- A single refractive index for all particles means that AERONET assumes internal mixing for all particles.

AERONET retrievals sometimes attribute fine mode absorption to the coarse mode



AERONET retrievals sometimes attribute fine mode absorption to the coarse mode



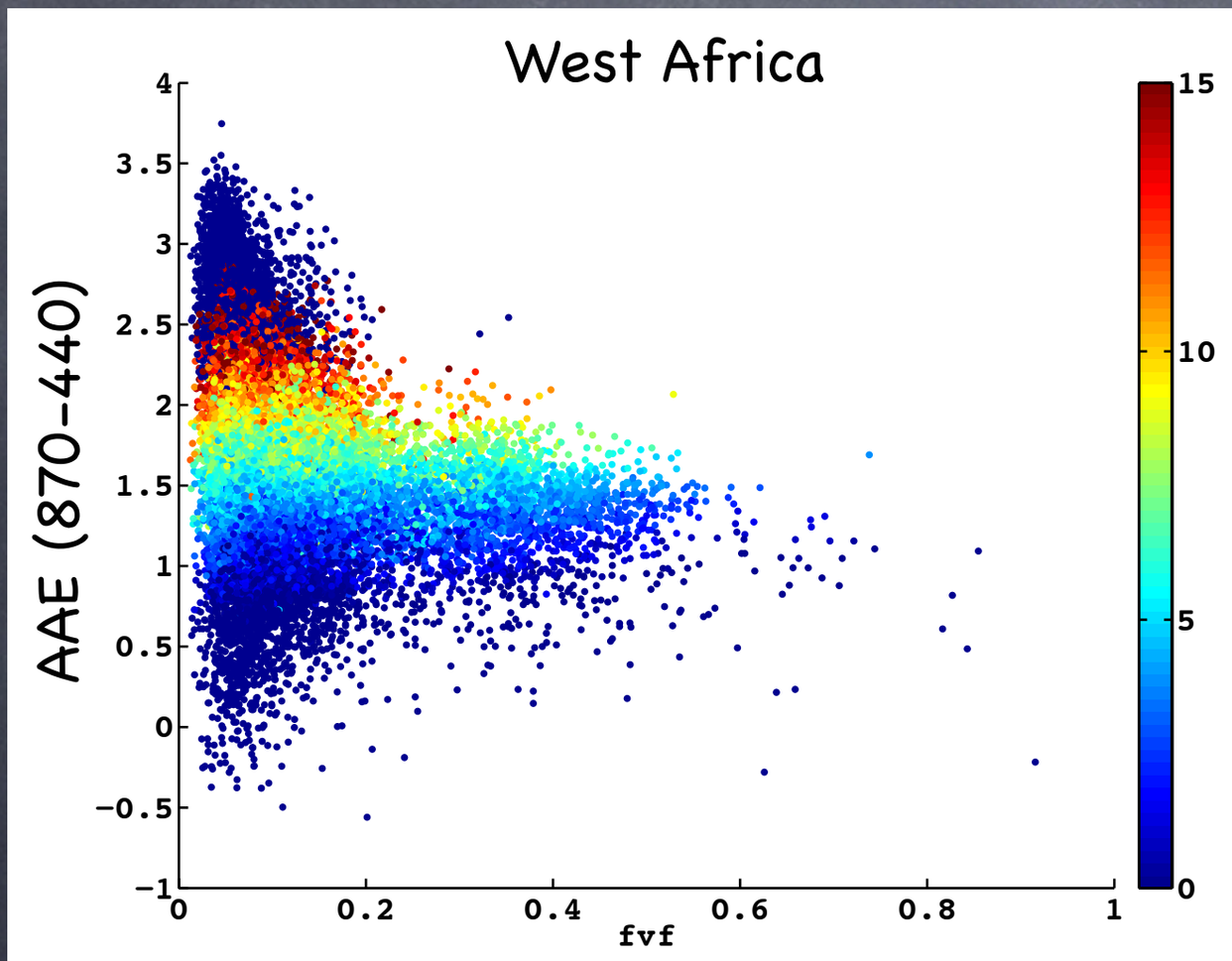
Dubovik et al (2002)	
Biomass Burning Location	Coarse Volume Fraction when AOD(440) = 0.5
Amazon Forest	0.29
S. Amer Cerrado	0.52
African Savanna	0.43
Boreal Forest	0.29

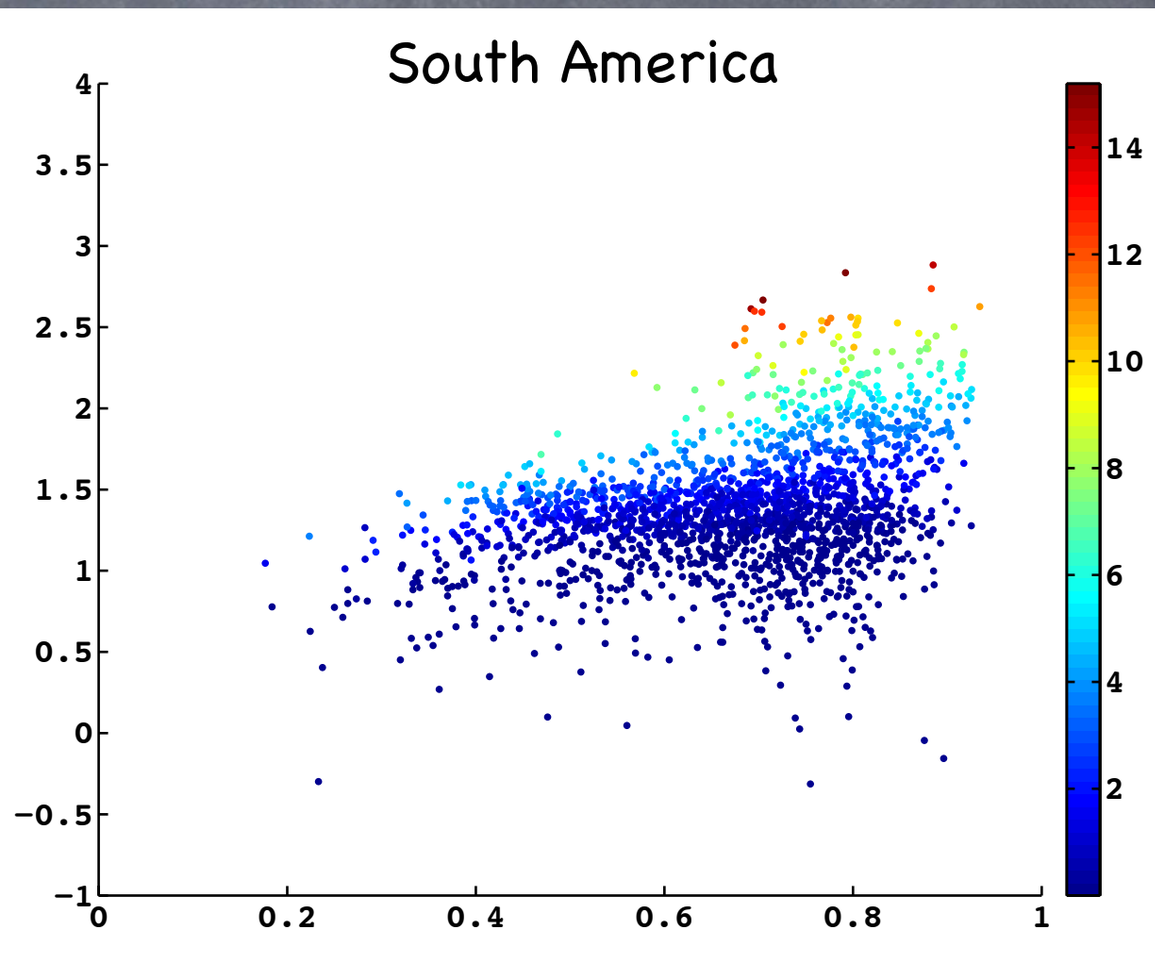
Conclusions

- Retrieval initially deduces two absorbing components in each aerosol mode (BrC/BC in fine mode, hematite/goethite in coarse mode)
- Retrieval makes adjustments to both modes if thresholds are exceeded (BrC/BC > 20 for fine mode, k > 0.0042 for coarse mode).
- Seasonal results at West Africa and South America are consistent with expectations.
- Discussed results in context of AAE.

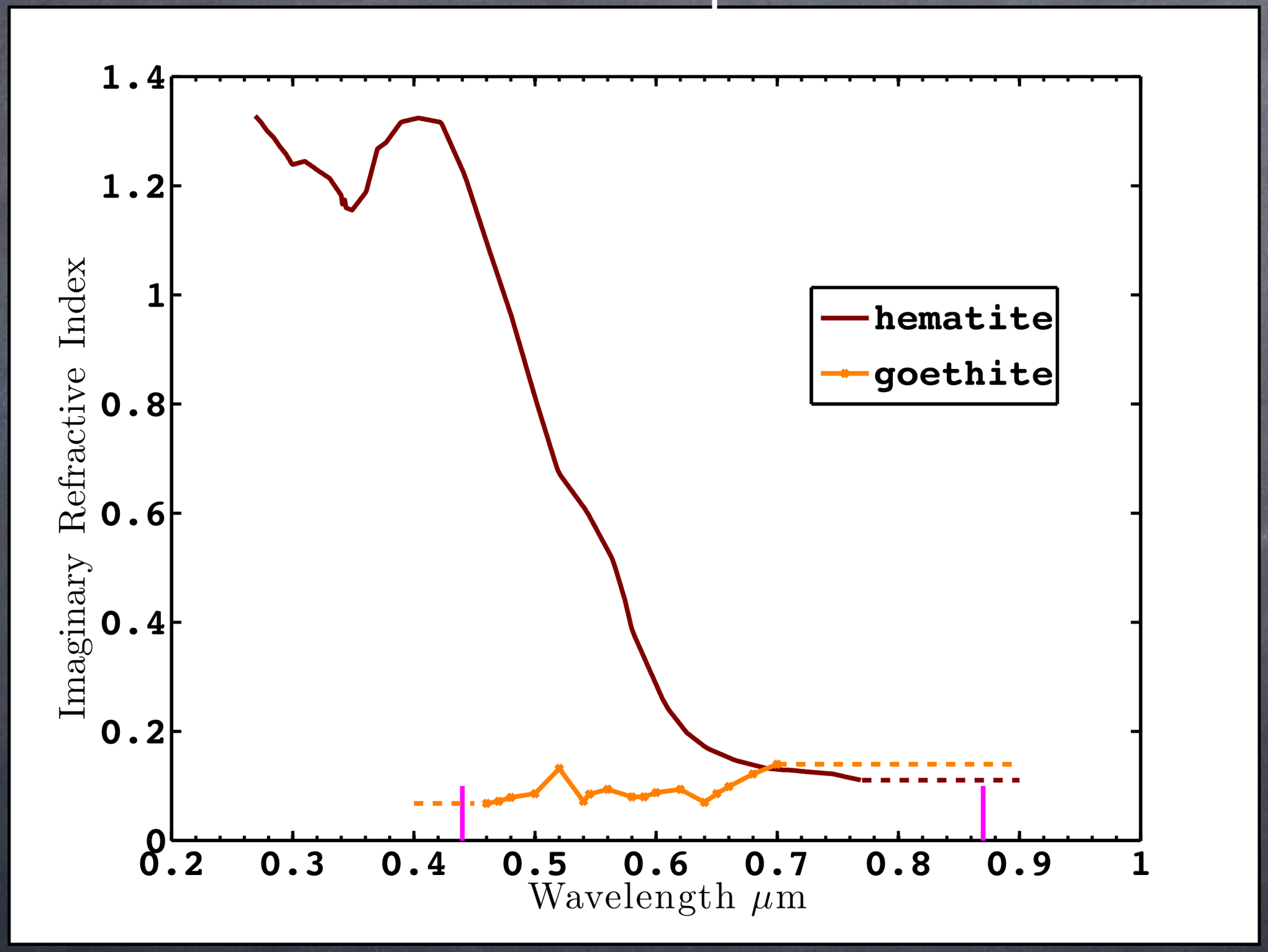
Appendix

OC/BC ratio increases with increasing AAE at all fine volume fractions.

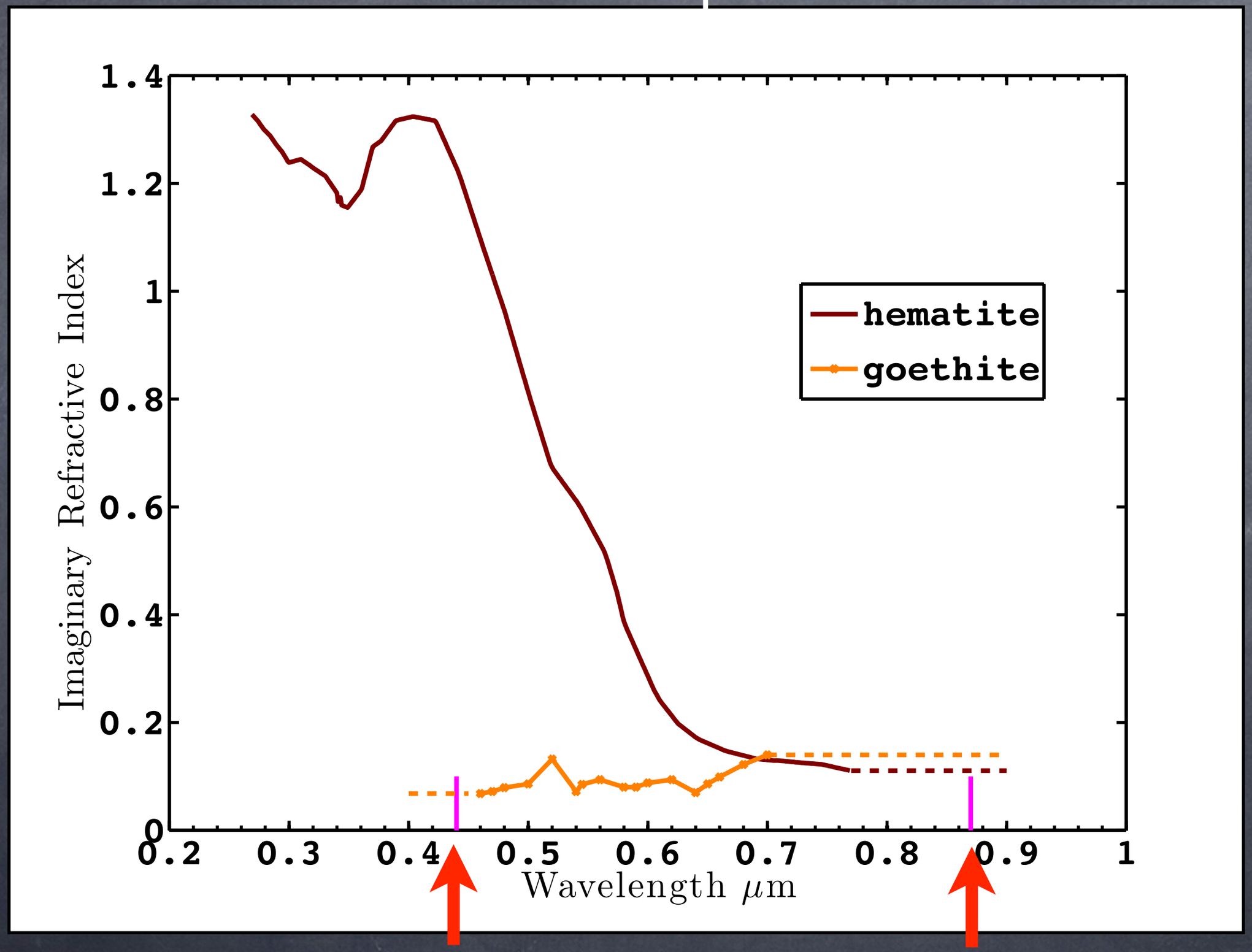


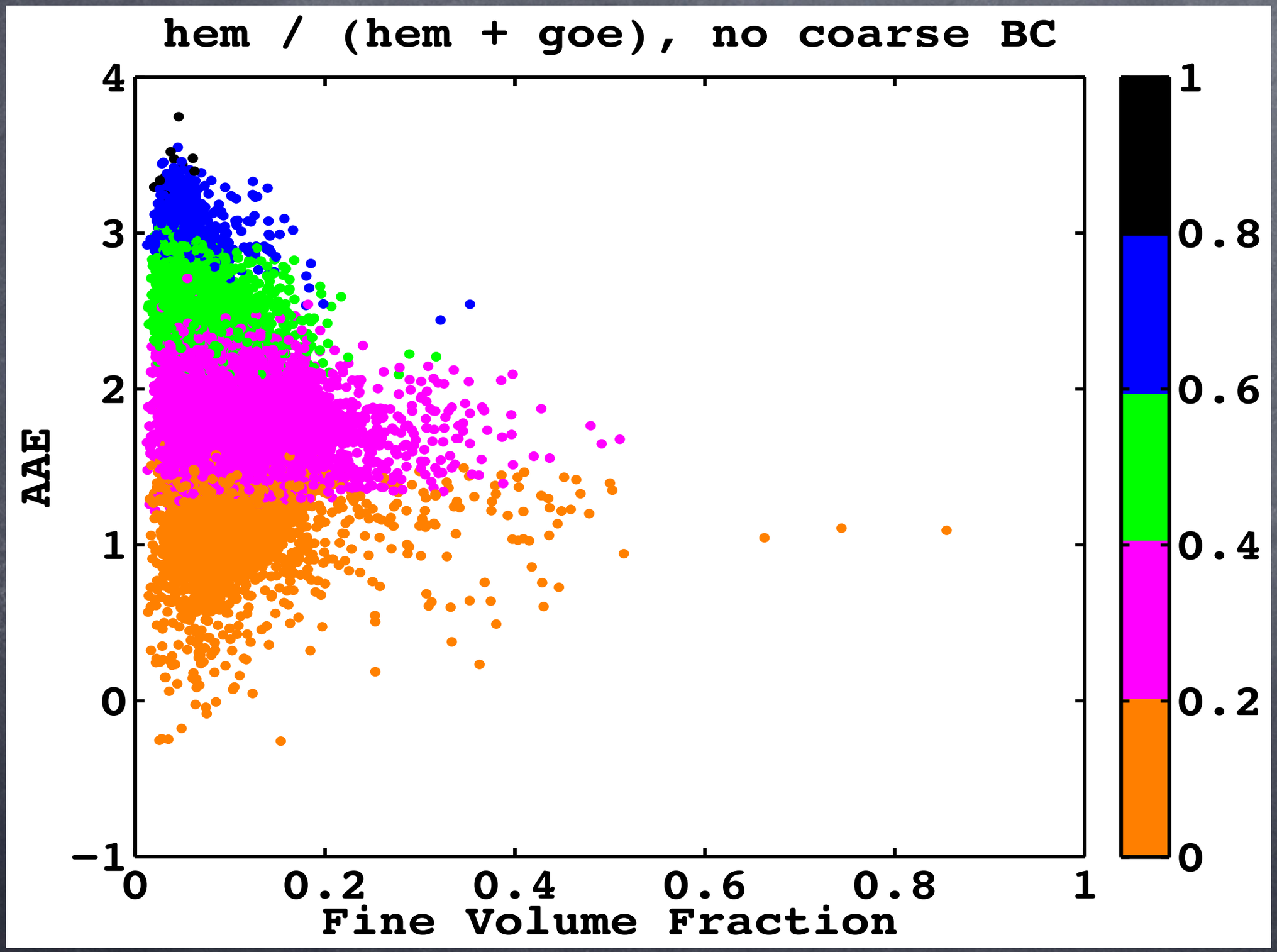


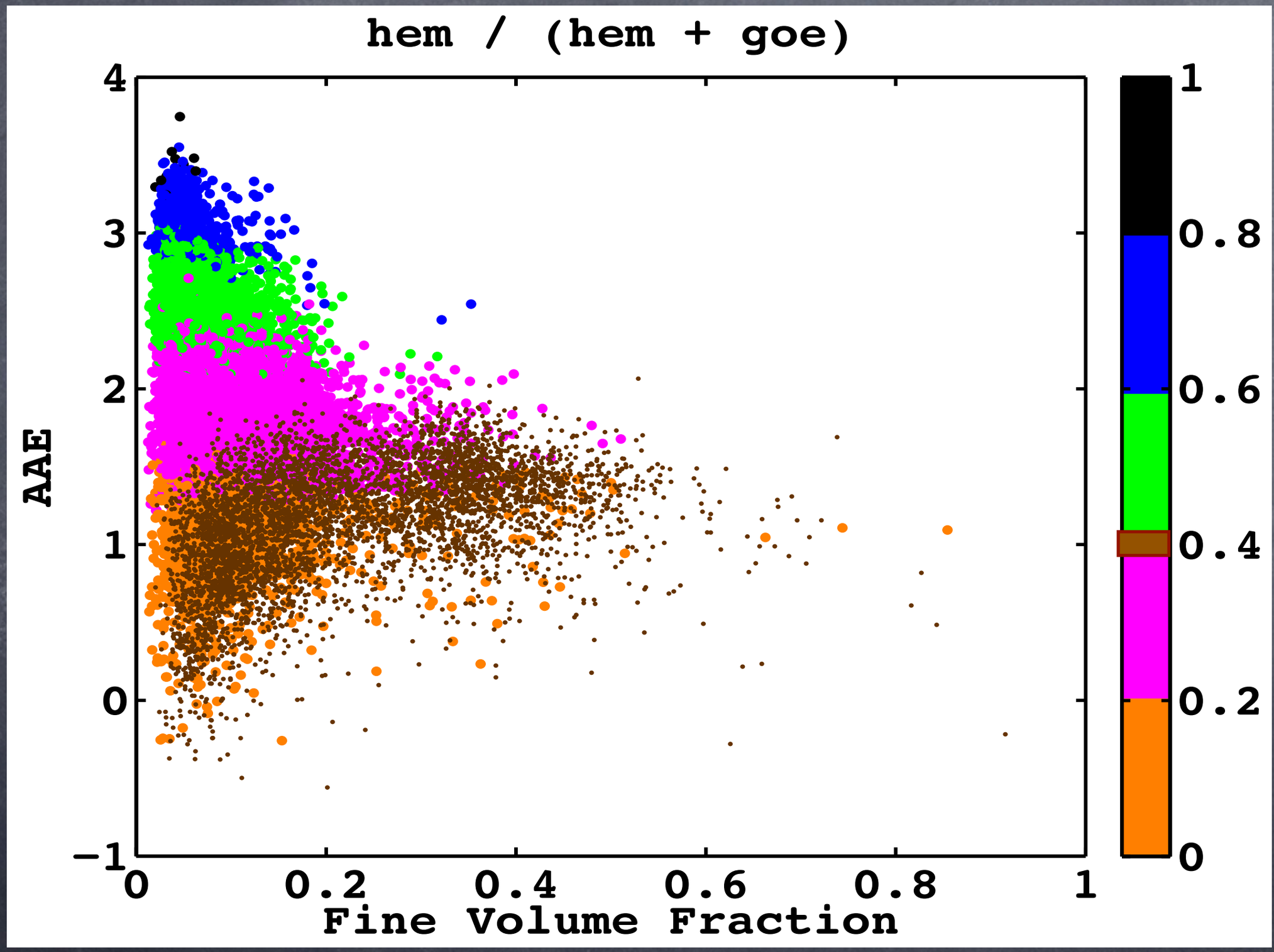
How to retrieve two absorbing species from refractive index: example for free iron.



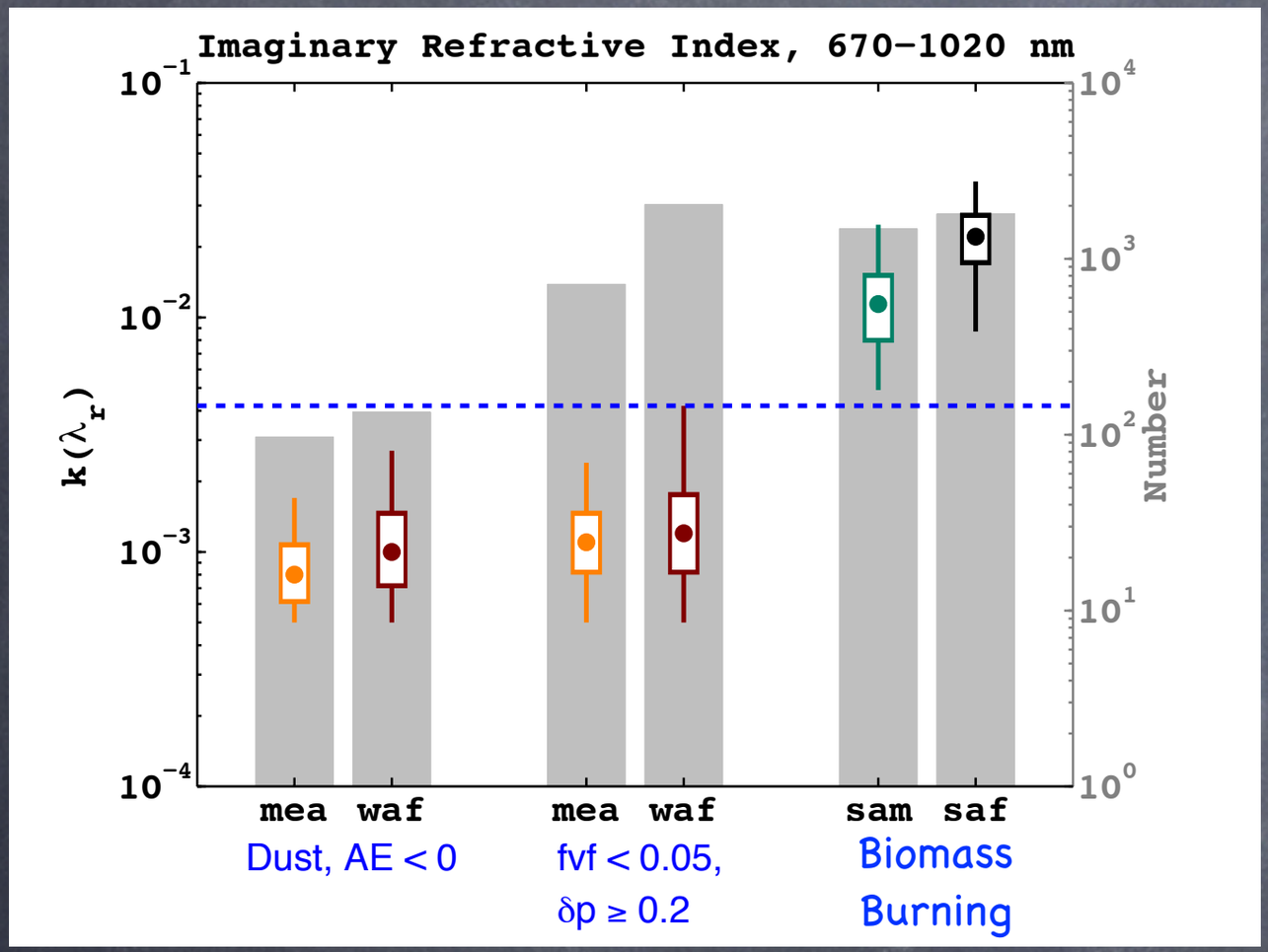
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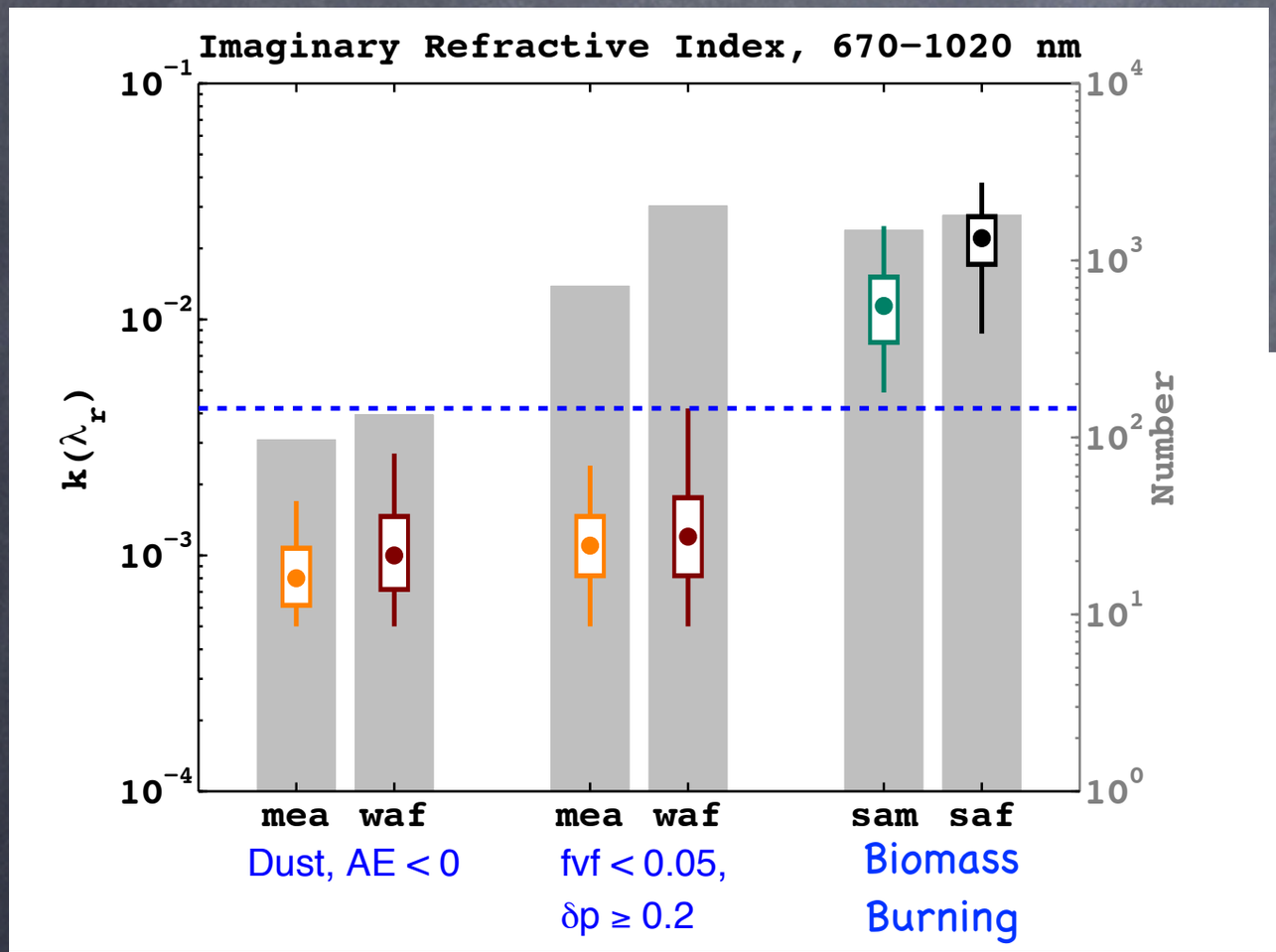

hem / (hem + goe), no coarse BC
AAE
Fine Volume Fraction
4
3
2
1
0
−1
0
0.2
0.4
0.6
0.8
1
1
0.8
0.6
0.4
0.2
0


hem / (hem + goe)
AAE
Fine Volume Fraction
4
3
2
1
0
−1
0
0.2
0.4
0.6
0.8
1
1
0.8
0.6
0.4
0.2
0

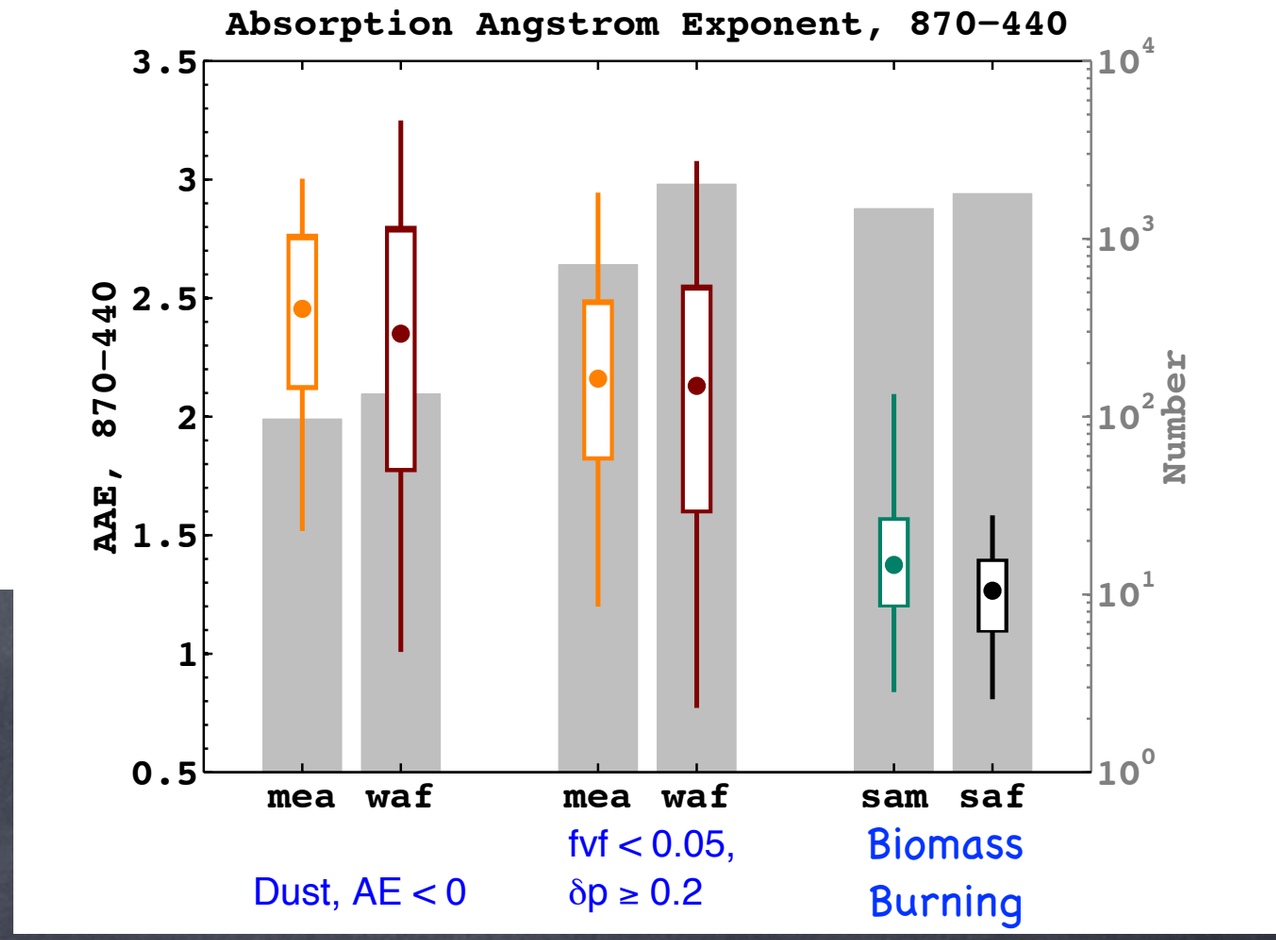
There is a clear separation between biomass burning and dust in imaginary refractive index space at 670-1020 nm

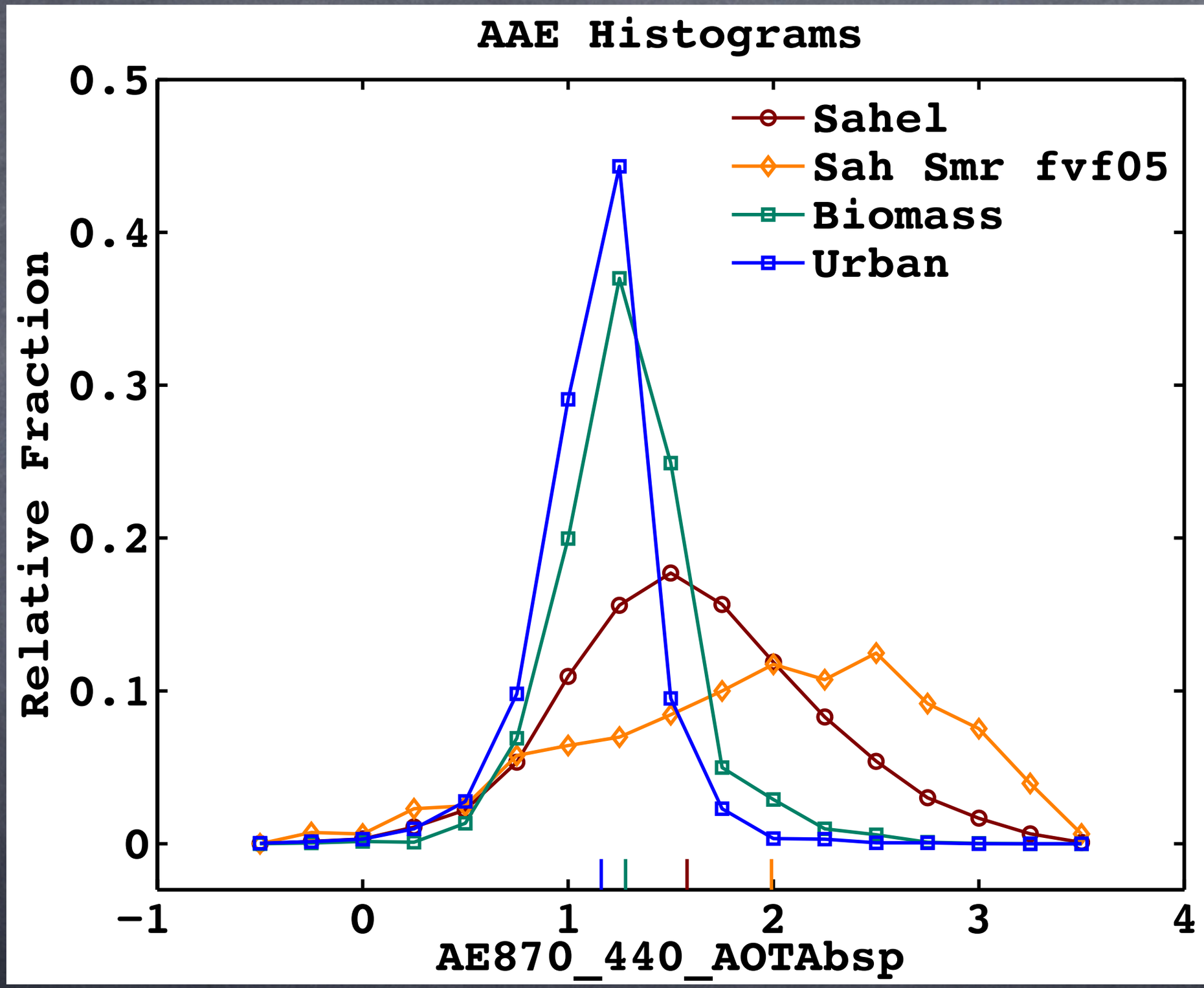


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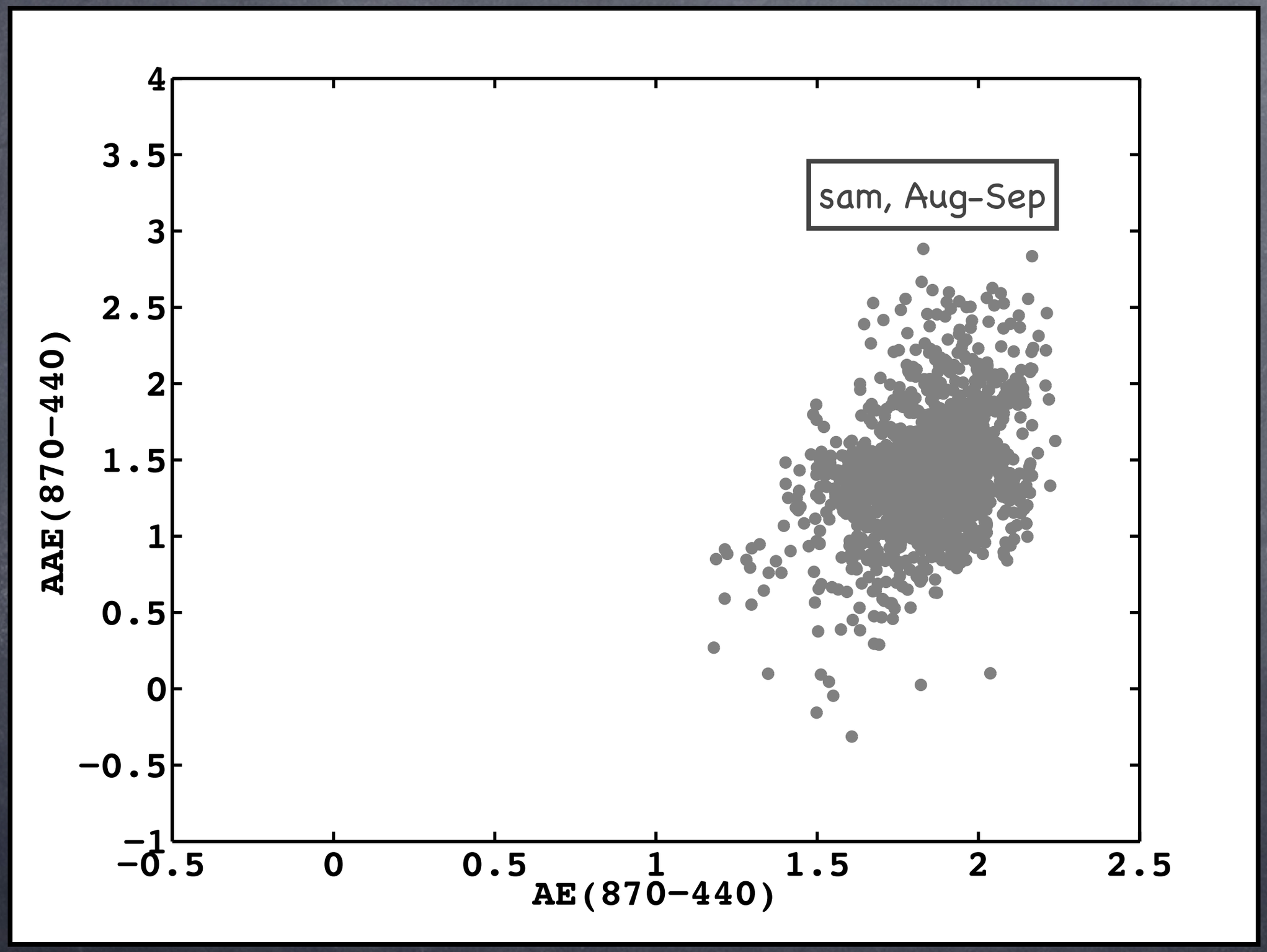


This is not the case for AAE!

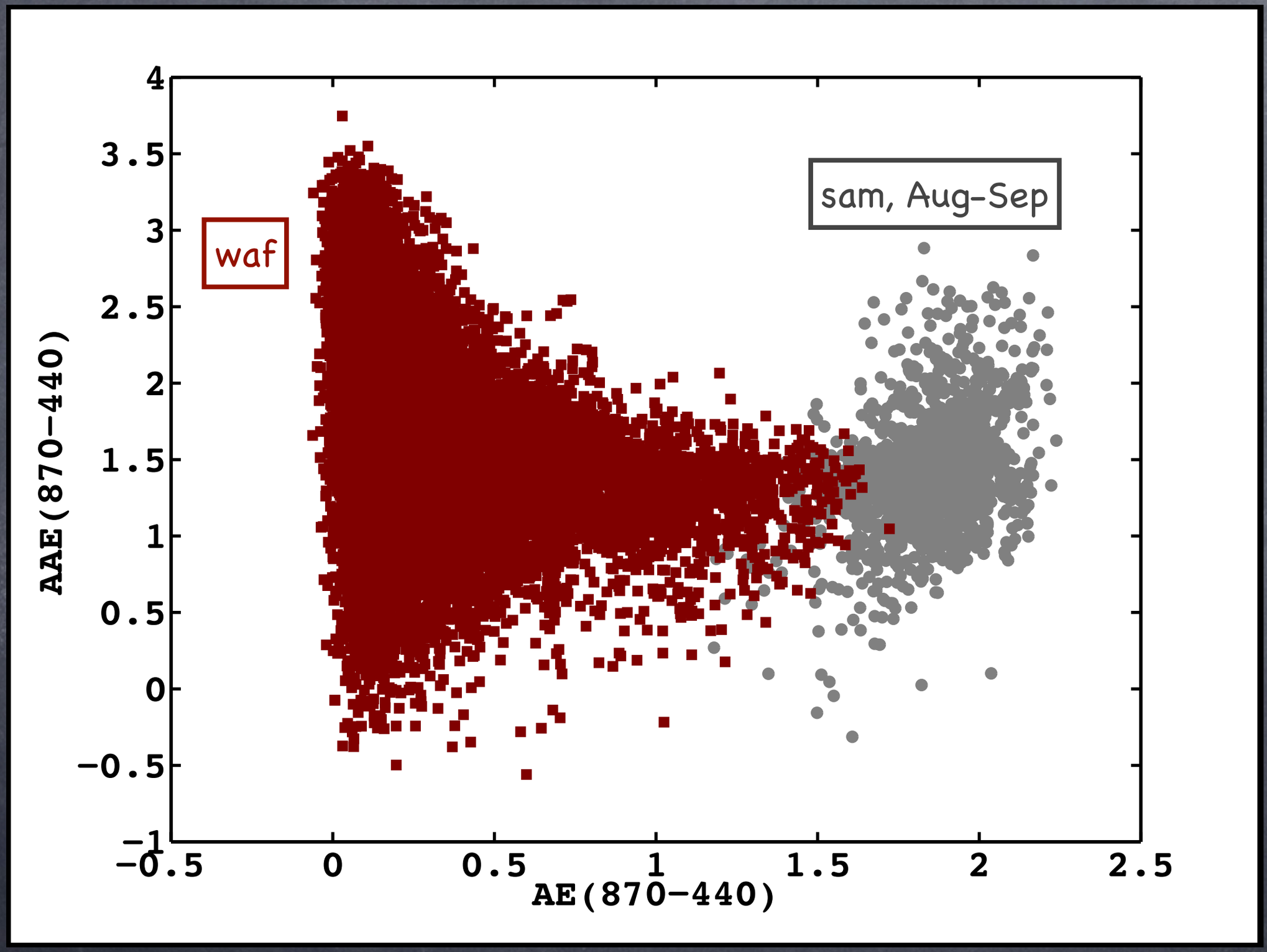



AAE Histograms
Sahel
Sah Smr fvf05
Biomass
Urban
Relative Fraction
0.5
0.4
0.3
0.2
0.1
0
−1
0
1
2
3
4
AE870_440_AOTAbsp

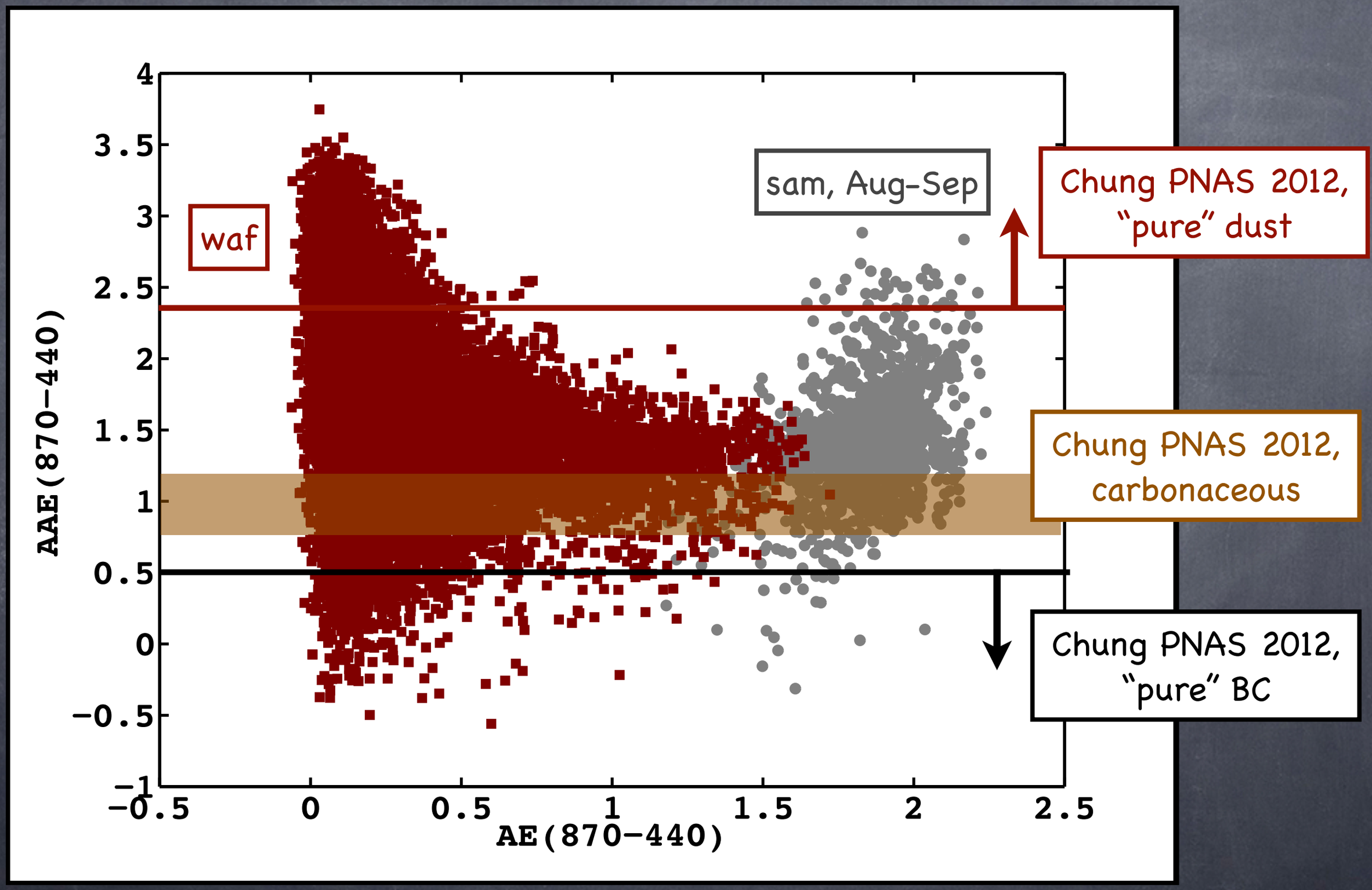
AAE Approach for separating aerosol absorption



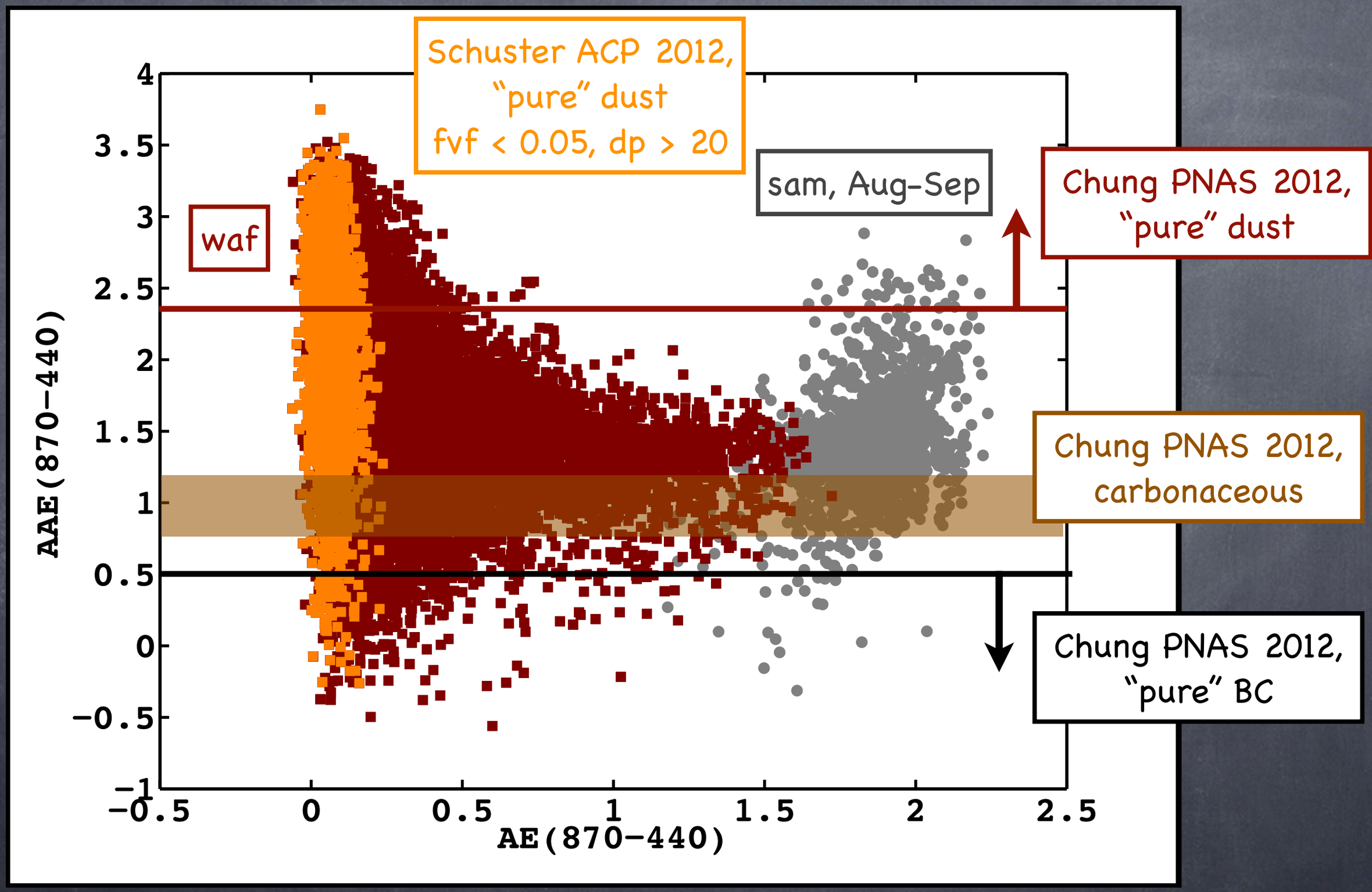
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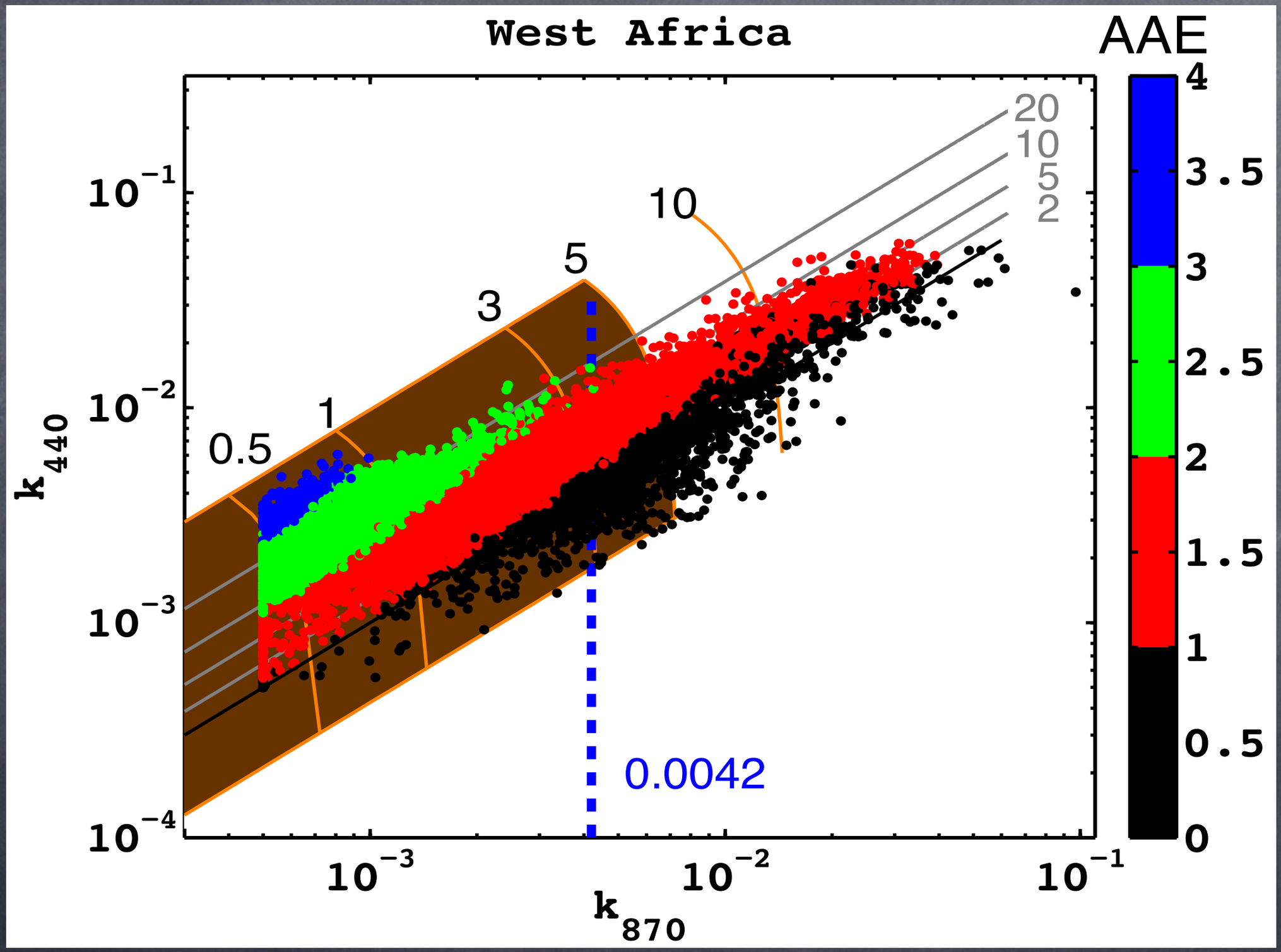
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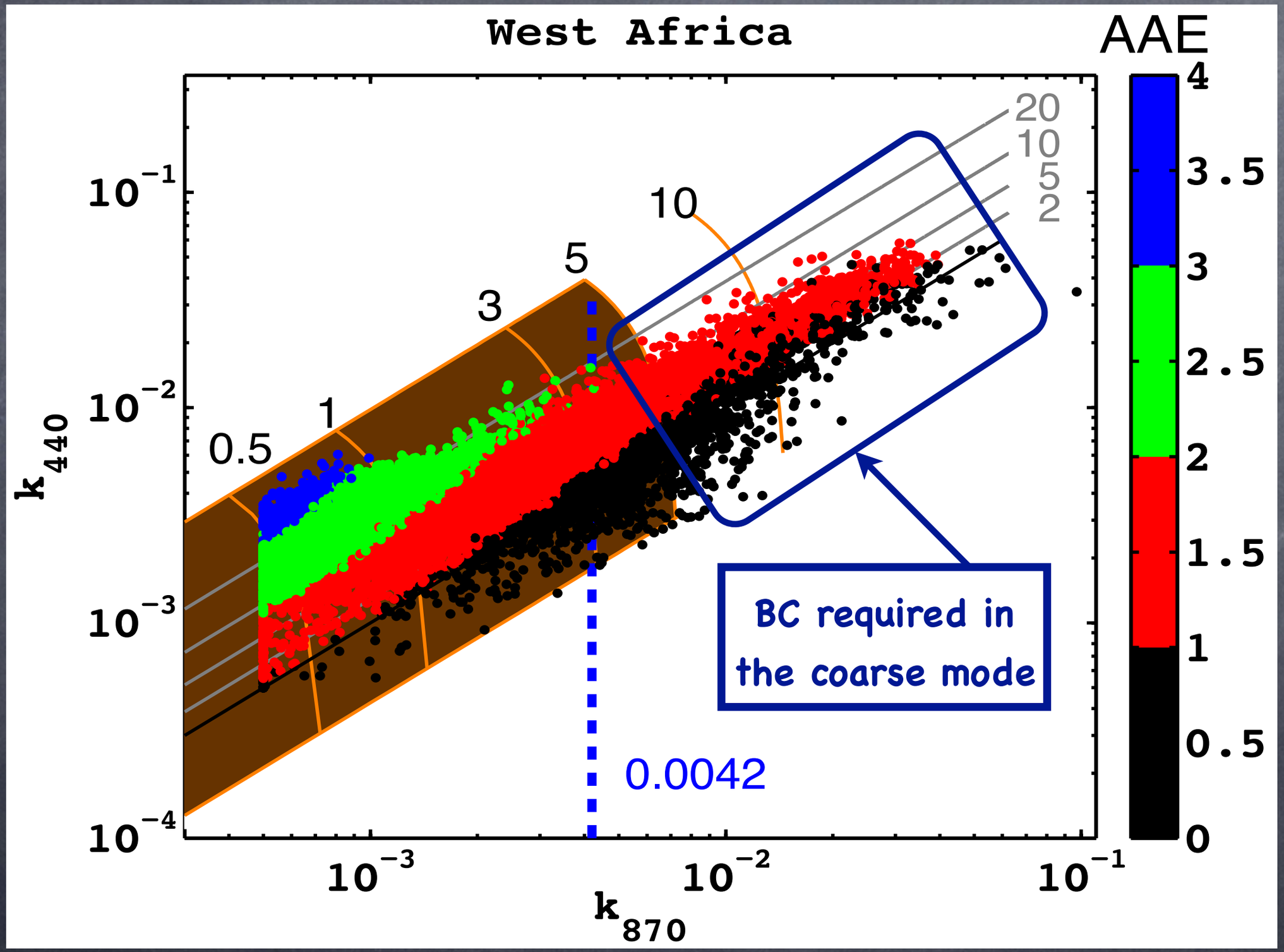
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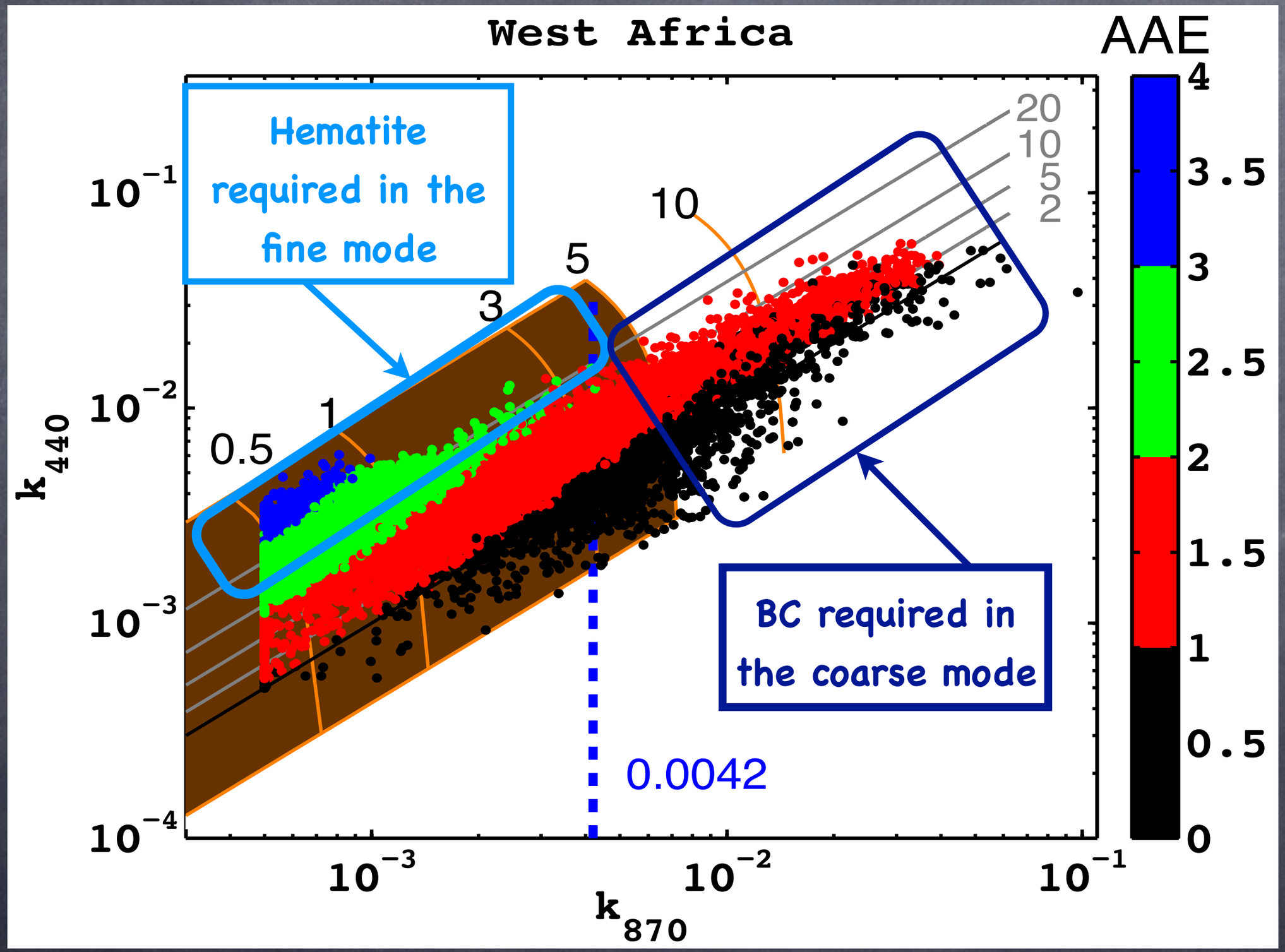
Now plot AERONET retrievals in k_{440}-k_{870} space

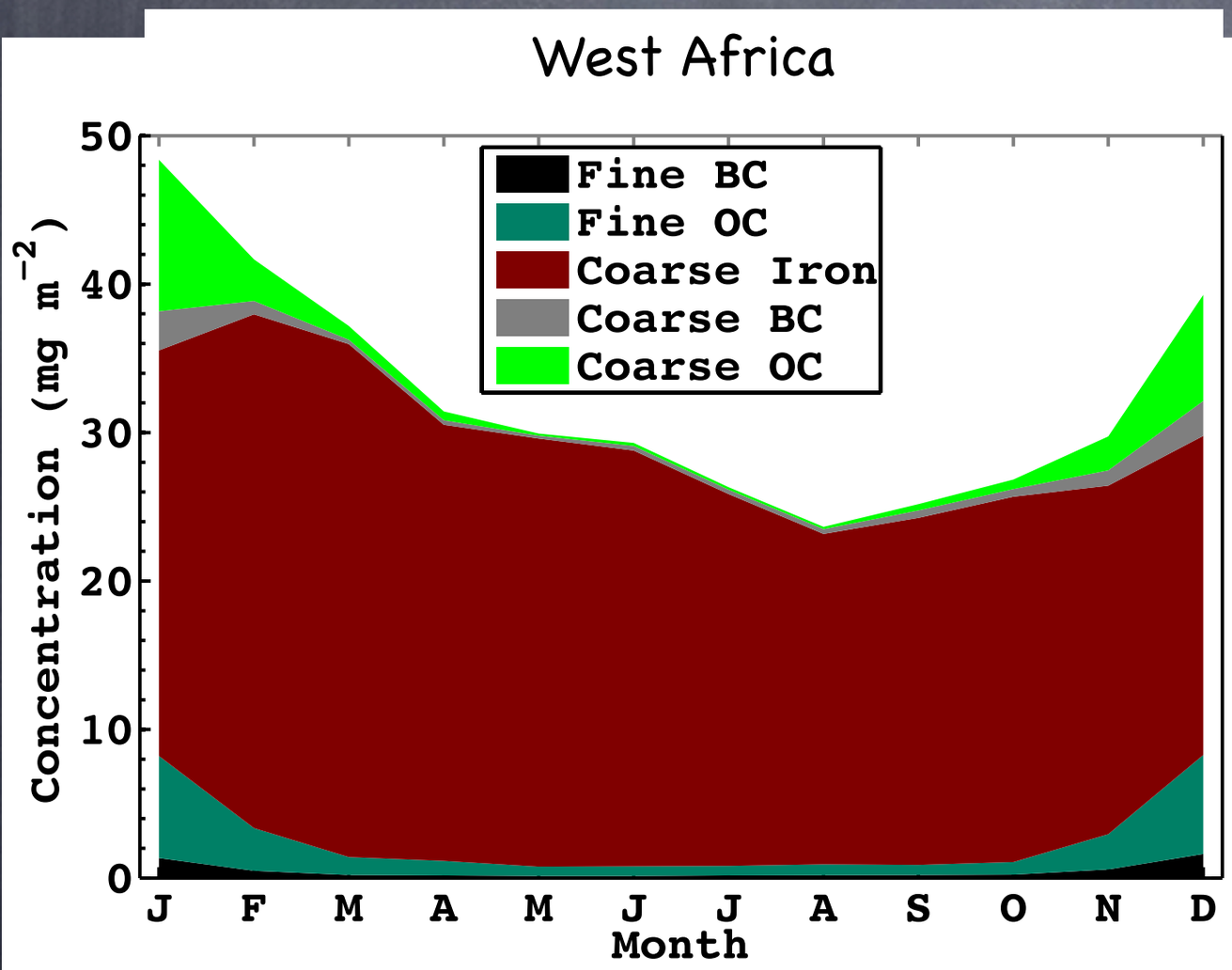


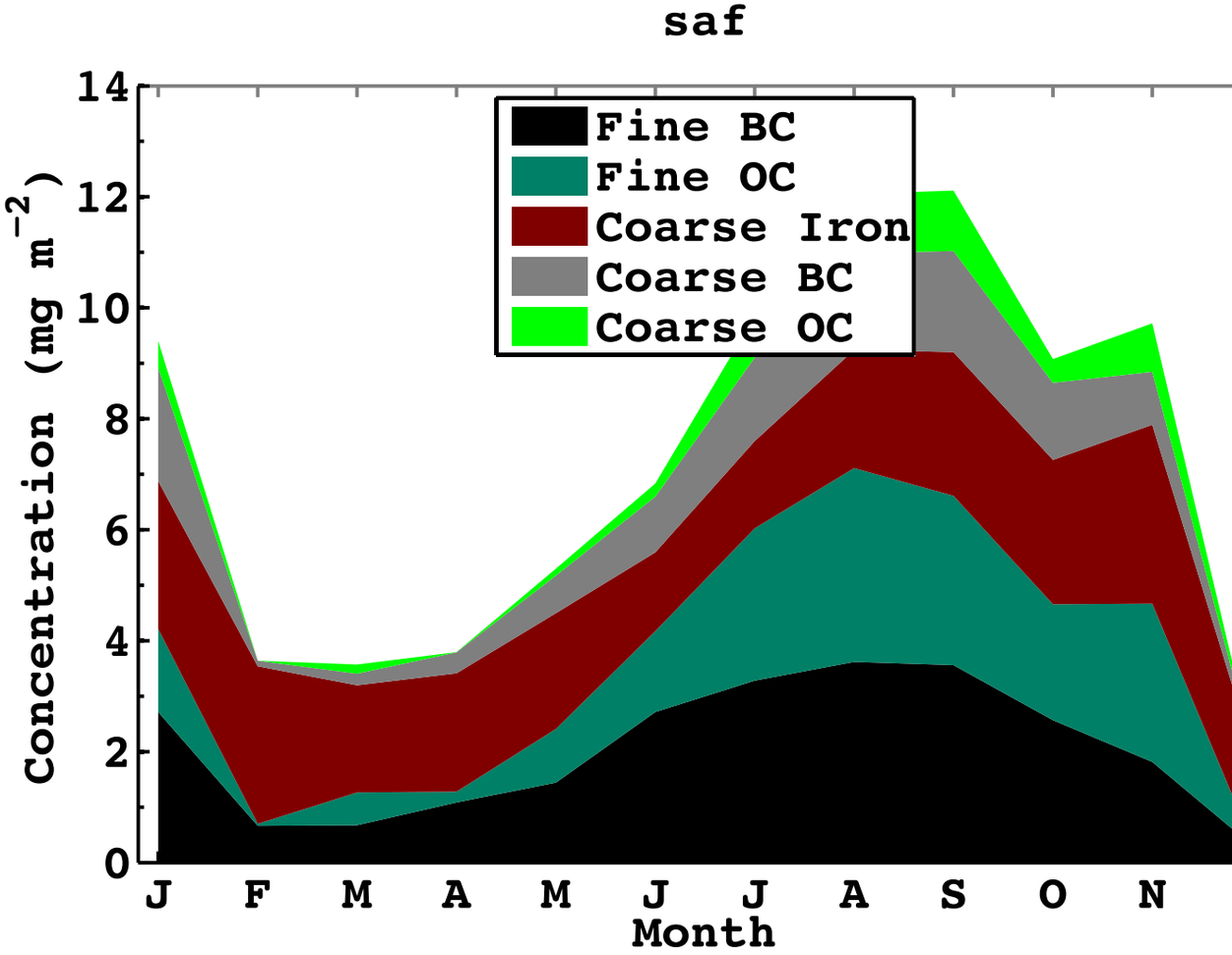
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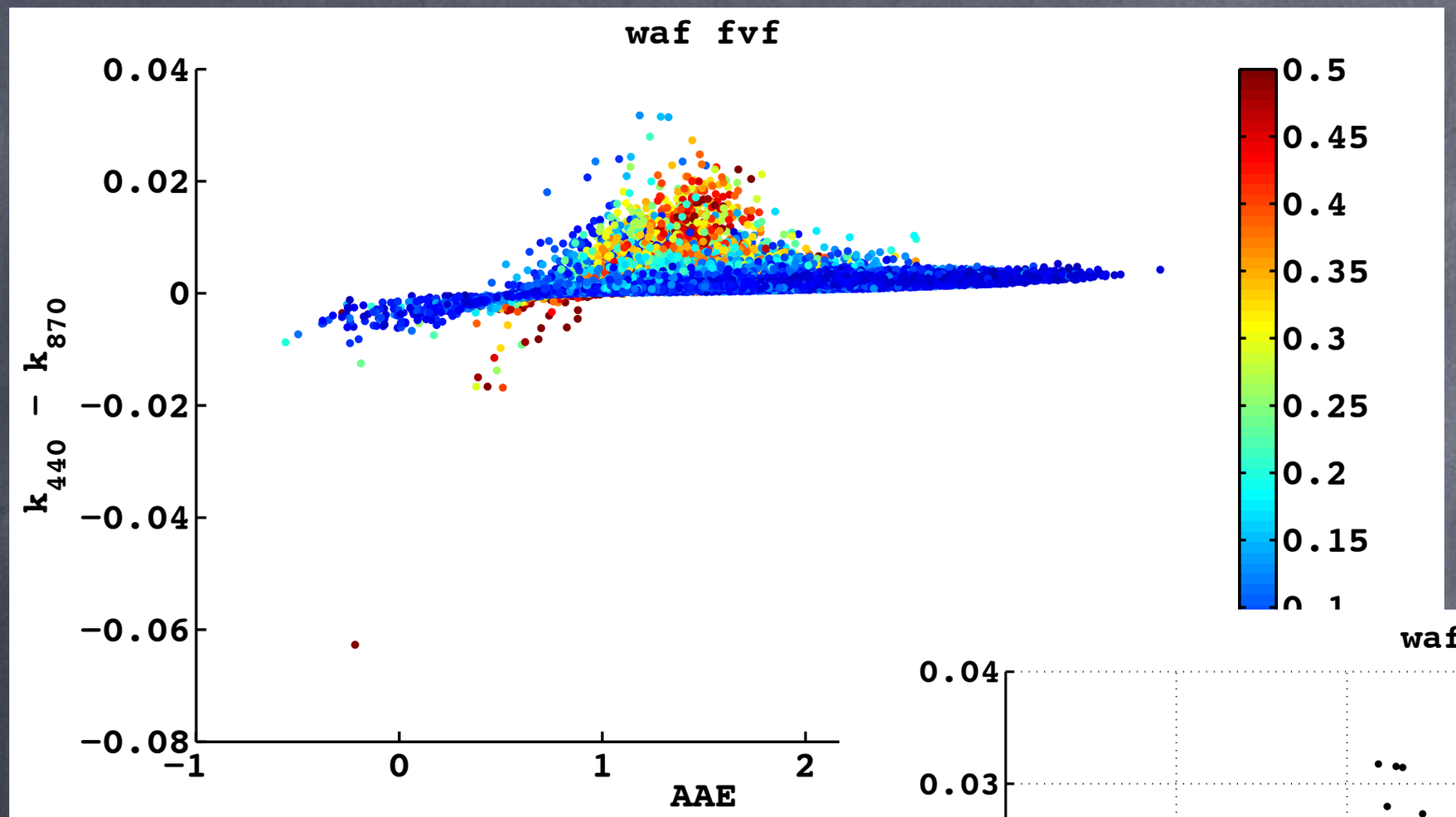


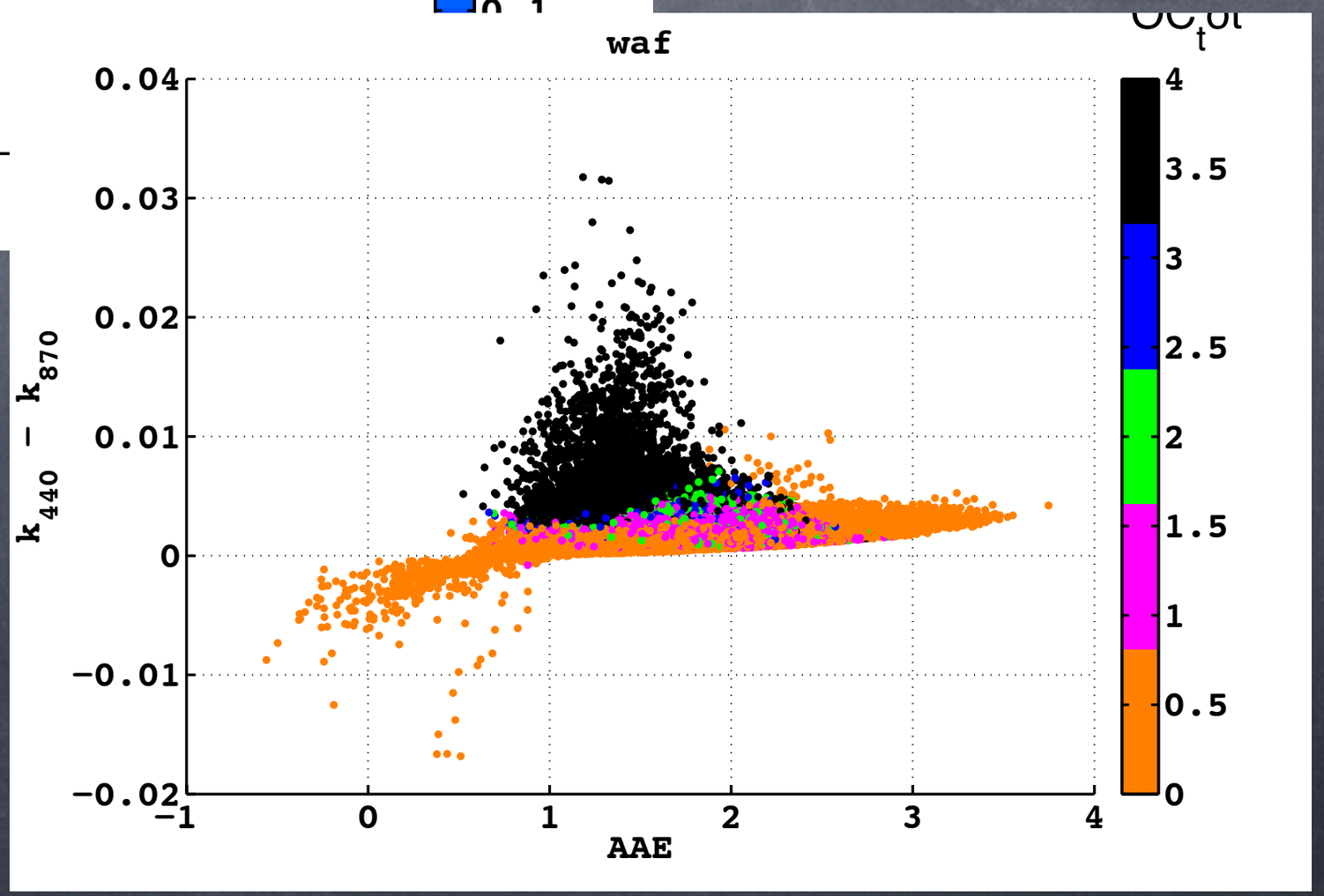
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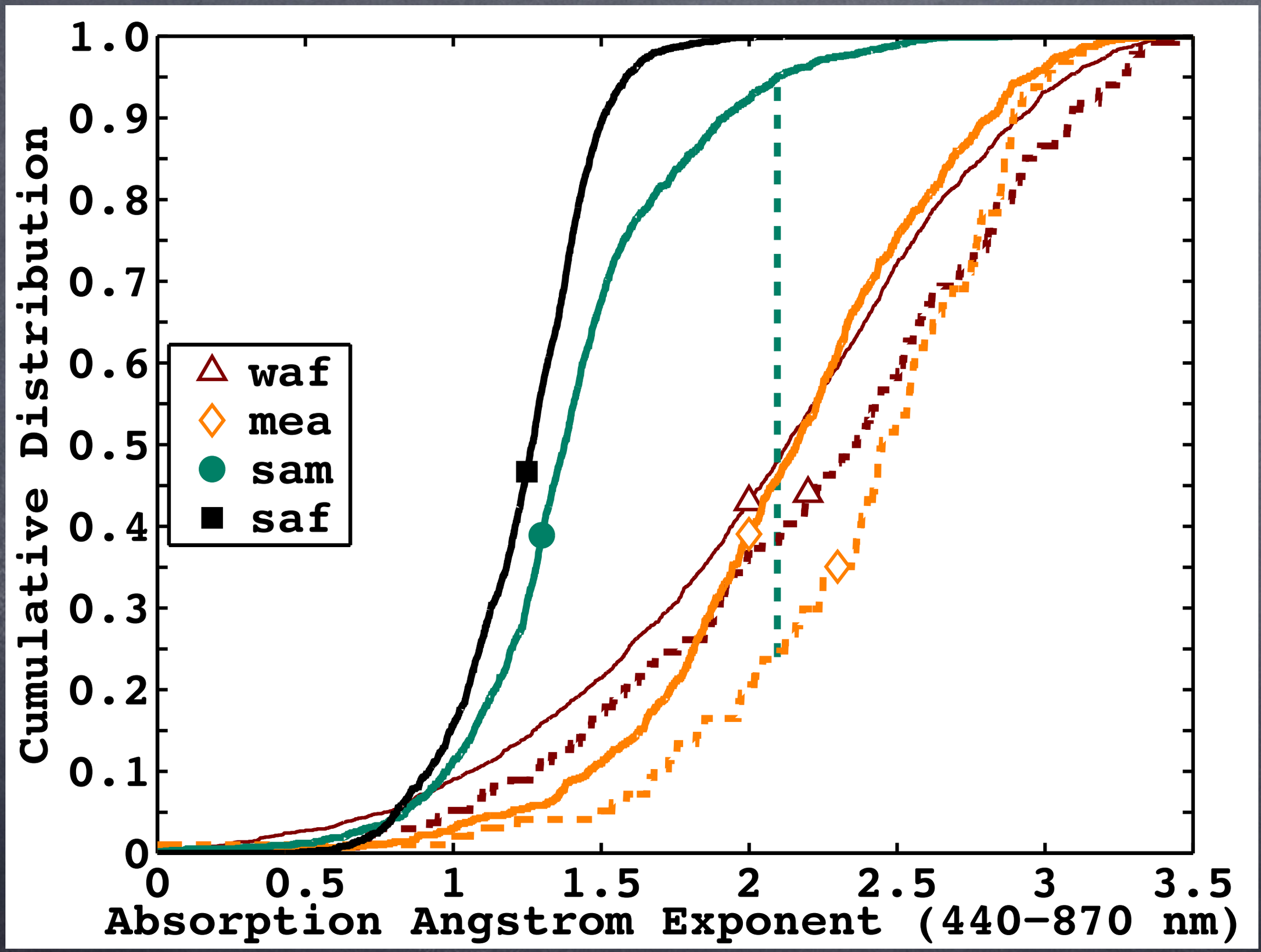



West Africa
Fine BC
Fine OC
Coarse Iron
Coarse BC
Coarse OC
Concentration (mg m^{-2})
0
10
20
30
40
50
J F M A M J J A S O N D
Month

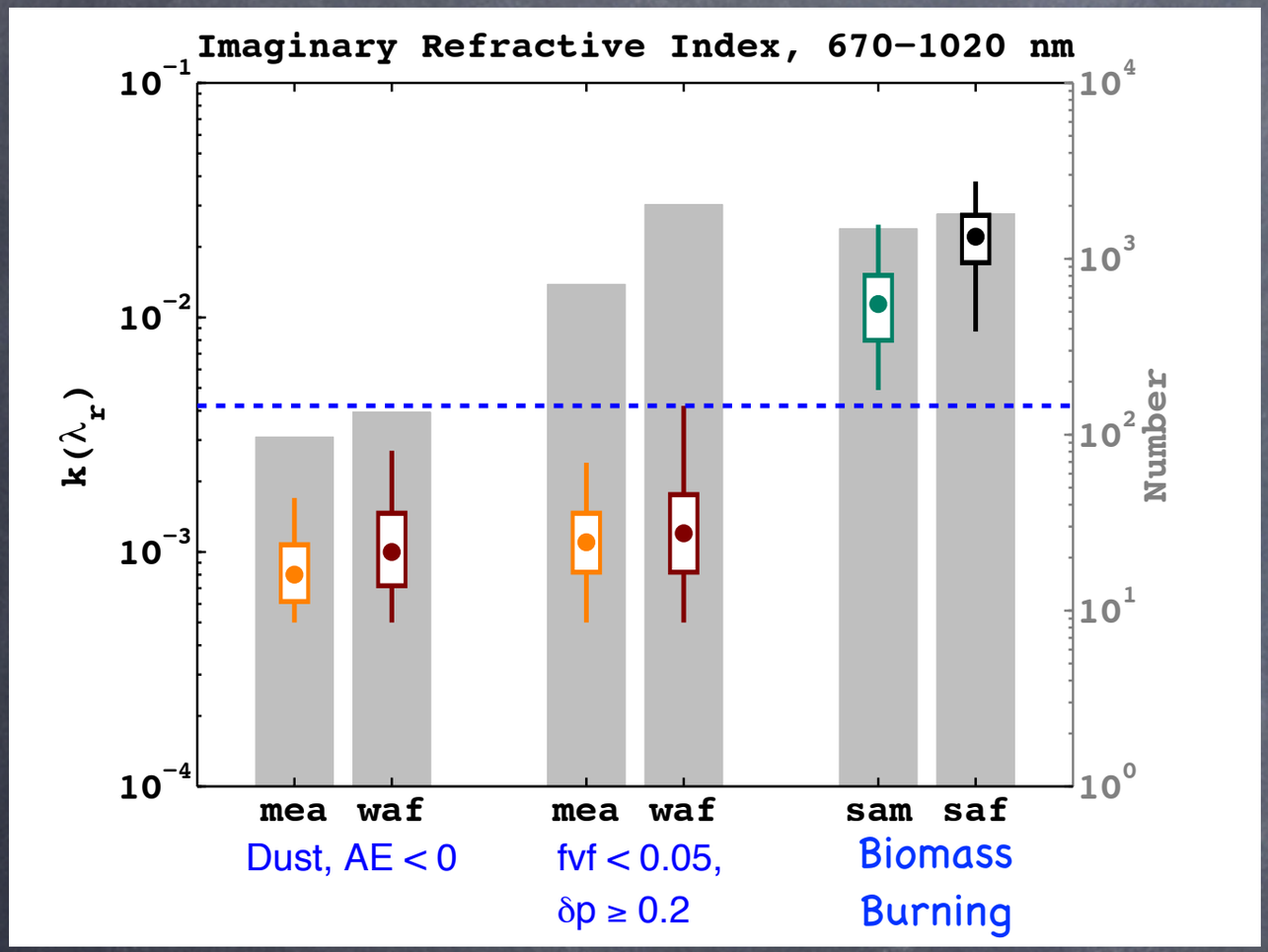

saf
Fine BC
Fine OC
Coarse Iron
Coarse BC
Coarse OC
Concentration (mg m^{-2})
0
2
4
6
8
10
12
14
J F M A M J J A S O N
Month


waf fvf
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−1
0
1
2
AAE
$k_{440} - k_{870}$
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1


waf
0.04
0.03
0.02
0.01
0
−0.01
−0.02
−1
0
1
2
3
4
AAE
$k_{440} - k_{870}$
OC_{tot}
4
3.5
3
2.5
2
1.5
1
0.5
0

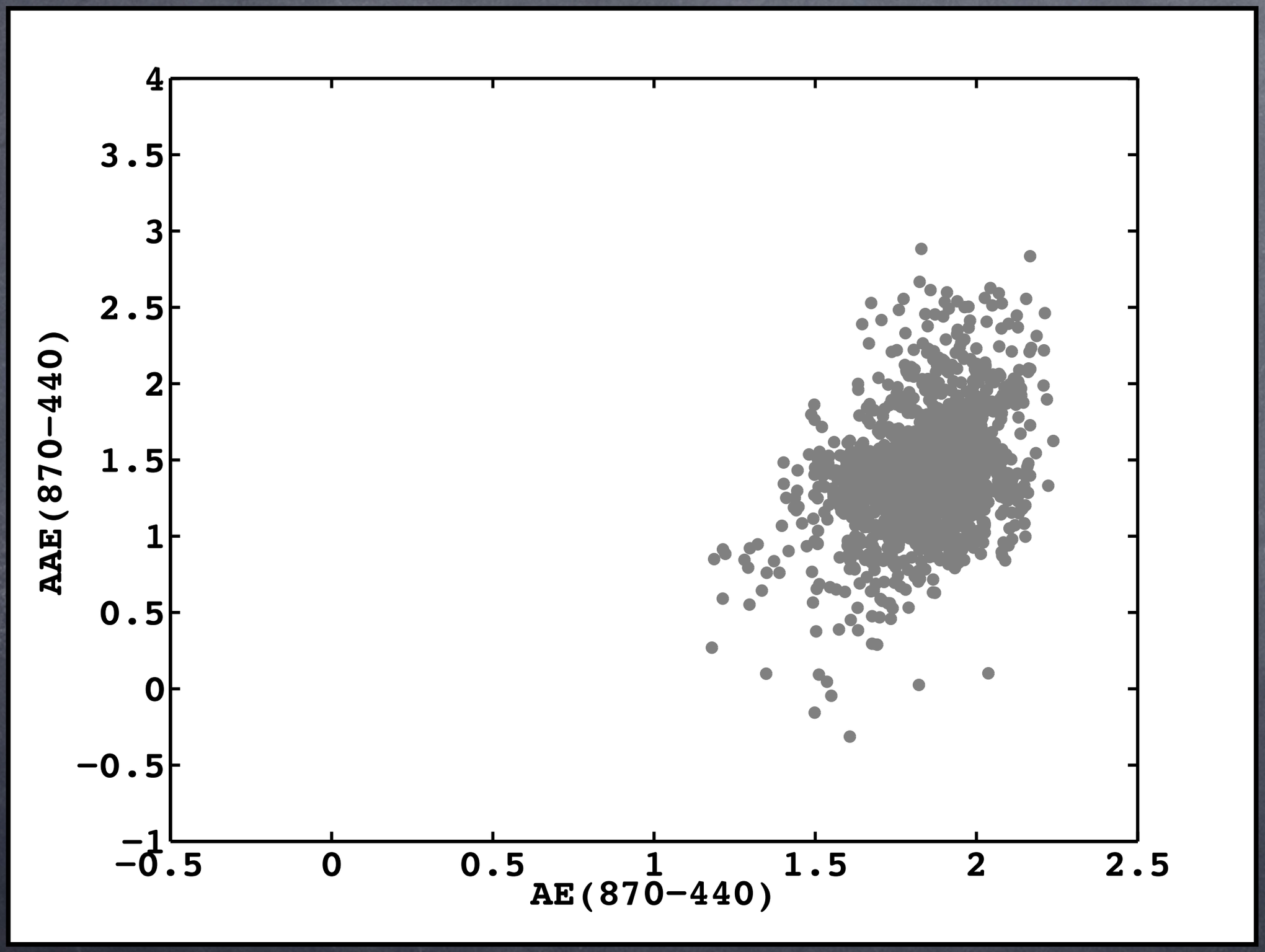

Cumulative Distribution
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
waf
mea
sam
saf
0
0.5
1
1.5
2
2.5
3
3.5
Absorption Angstrom Exponent (440–870 nm)

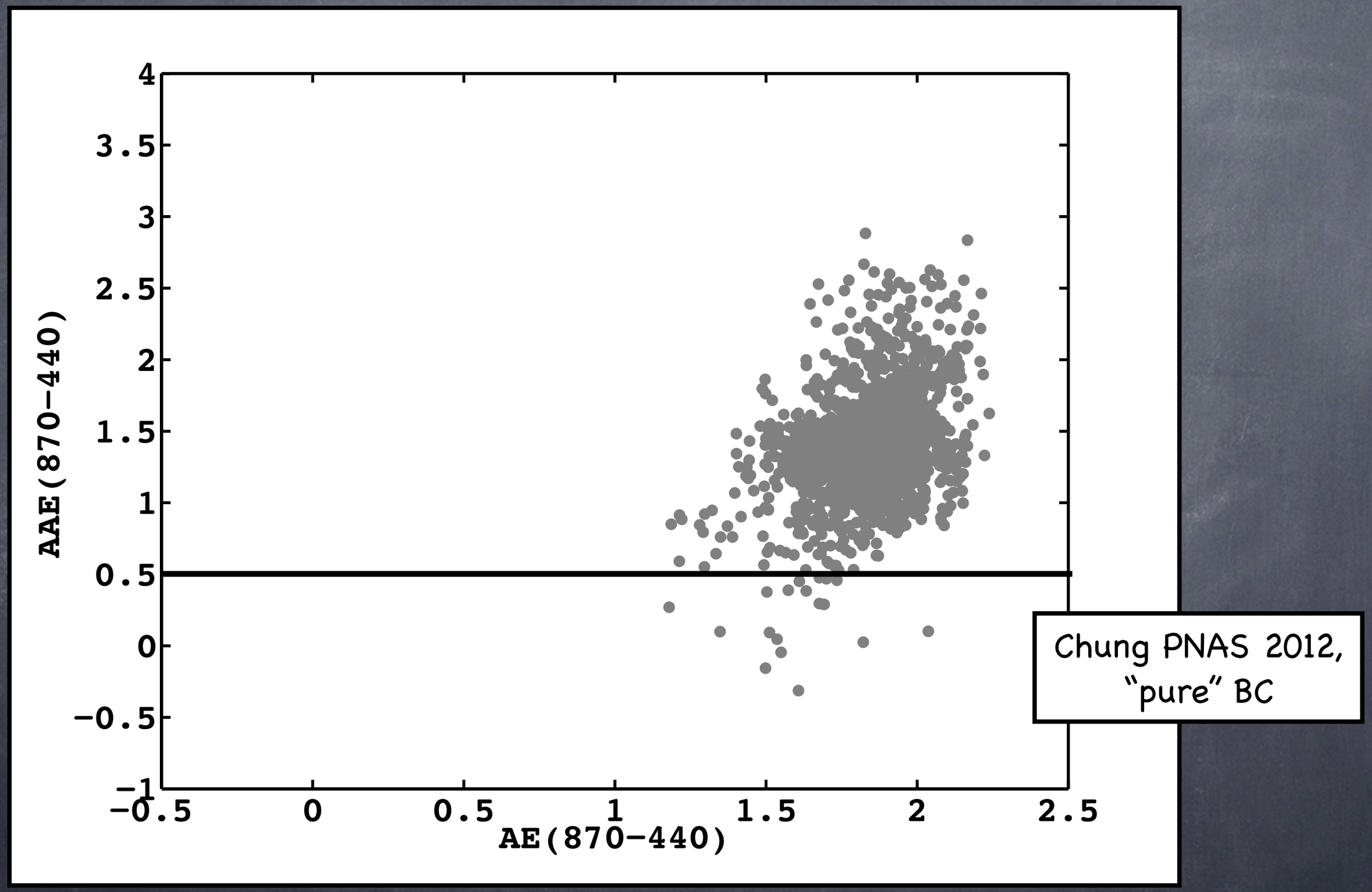
There is a clear separation between biomass burning and dust in imaginary refractive index space at 670-1020 nm

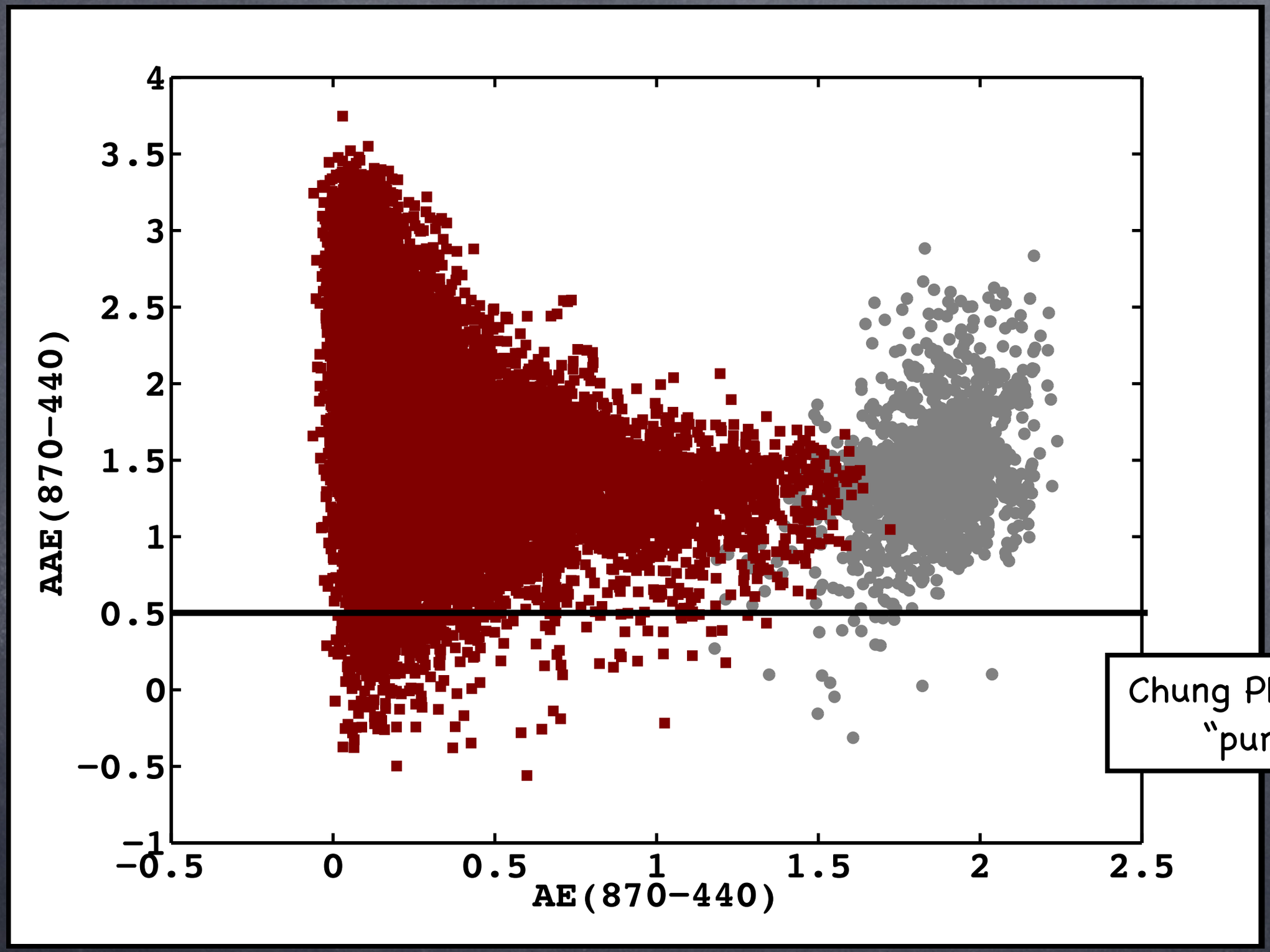


Chung PNAS:

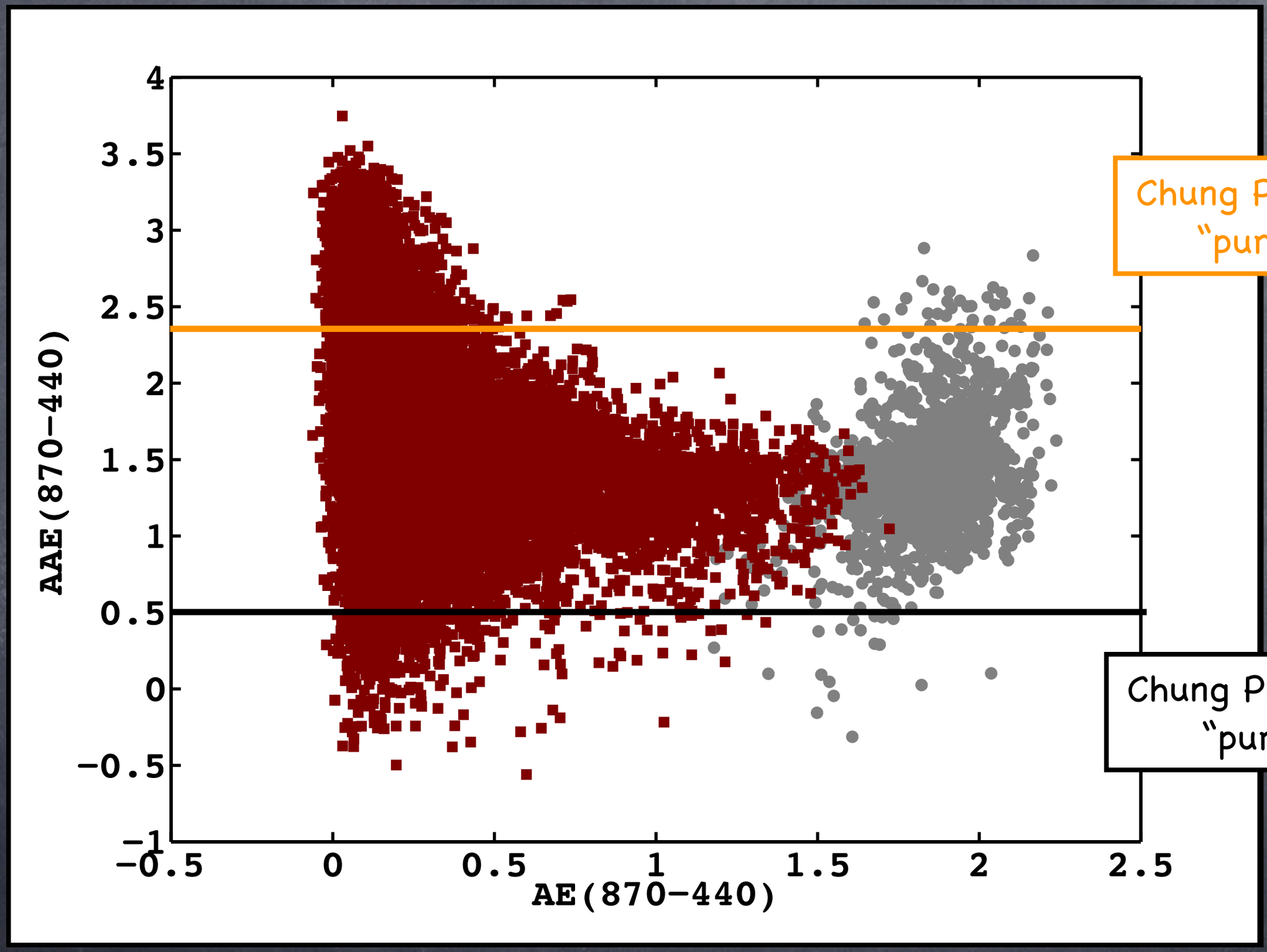
- Mean AAE for "pure" dust is 2.4, and the range is 2.2 to 2.6. This is from the 95+ percentile of AERONET AAEs in dust regions, where dust is defined as AE < 0.3.
- Carbonaceous AAE is 0.84 to 1.6, based upon AERONET.
- BC AAE is 0.5 (0.38-0.67), from lowest ?? percentile of AERONET AAE in urban regions and seasons
- OC AAE is 4.8 (3.5 to 6) from Magi reports of BC and OC AOD and Magi's SSA values of 0.19 and 0.85 for BC and OC (SAFARI dataset)


AAE(870−440)
AE(870−440)
4
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
−0.5
0
0.5
1
1.5
2
2.5


AAE(870–440)
AE(870–440)
4
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
−0.5
0
0.5
1
1.5
2
2.5
Chung PNAS 2012,
"pure" BC

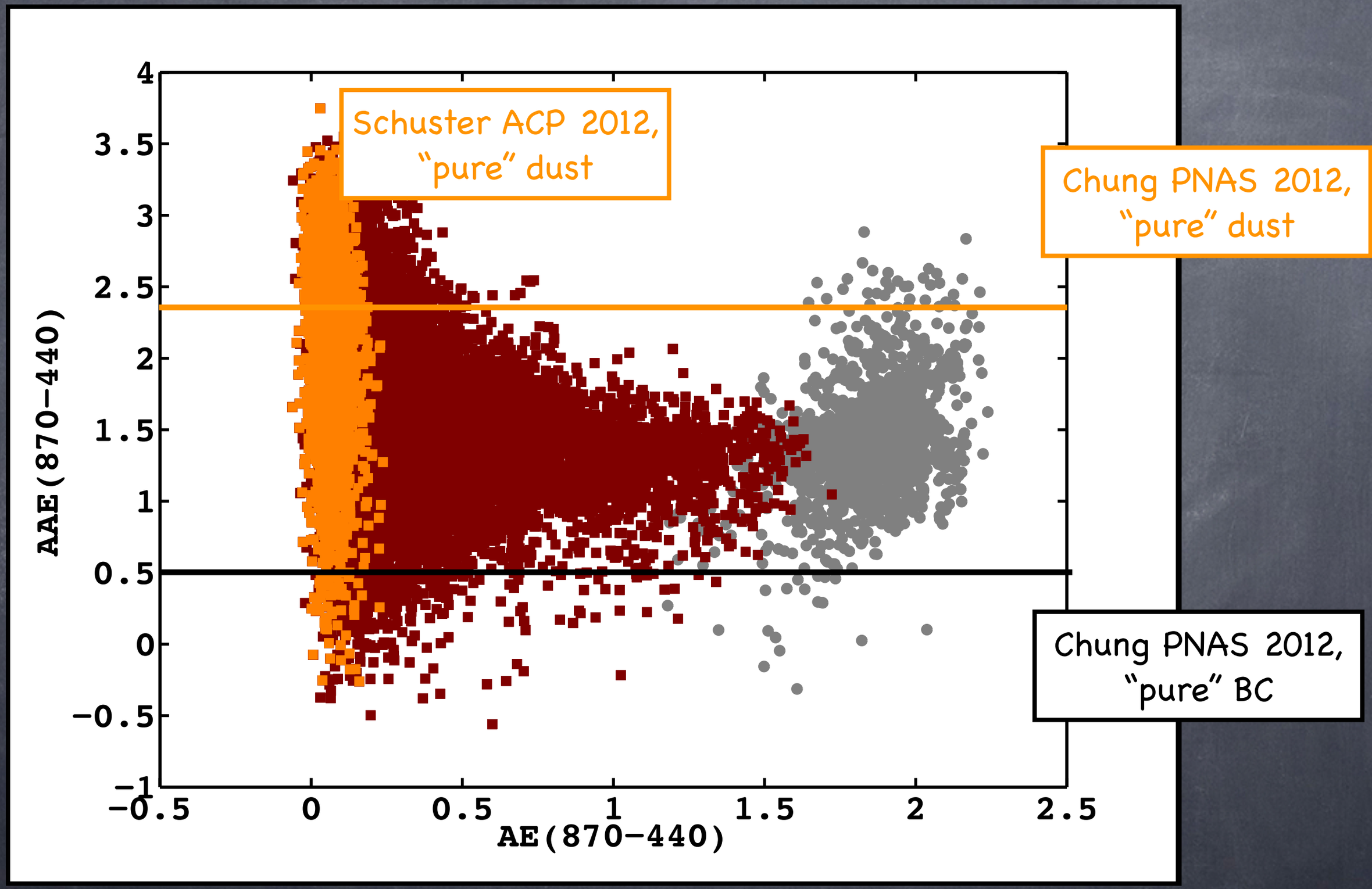


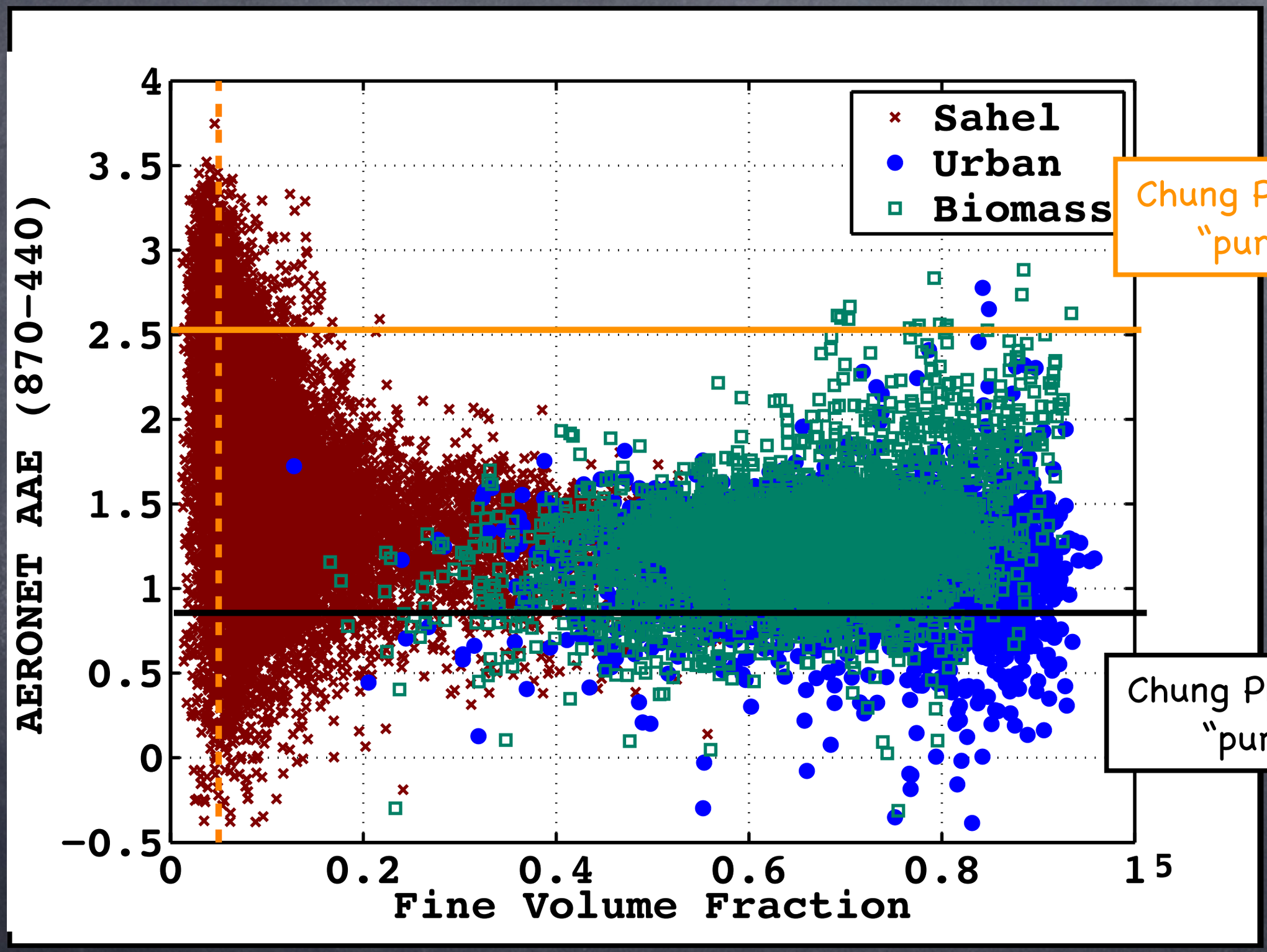
Chung PNAS 2012,
"pure" BC



Chung PNAS 2012, "pure" dust

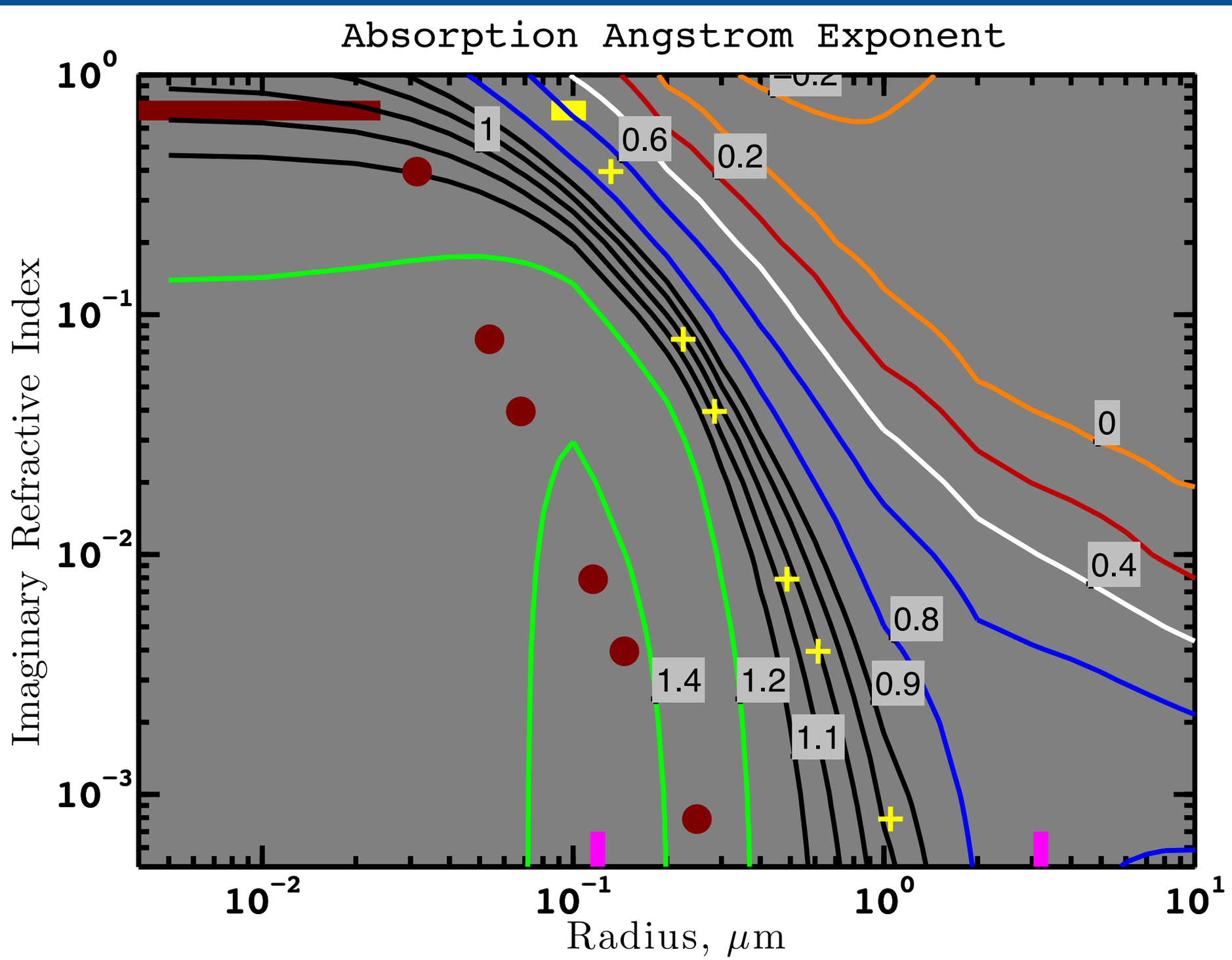
Chung PNAS 2012, "pure" BC

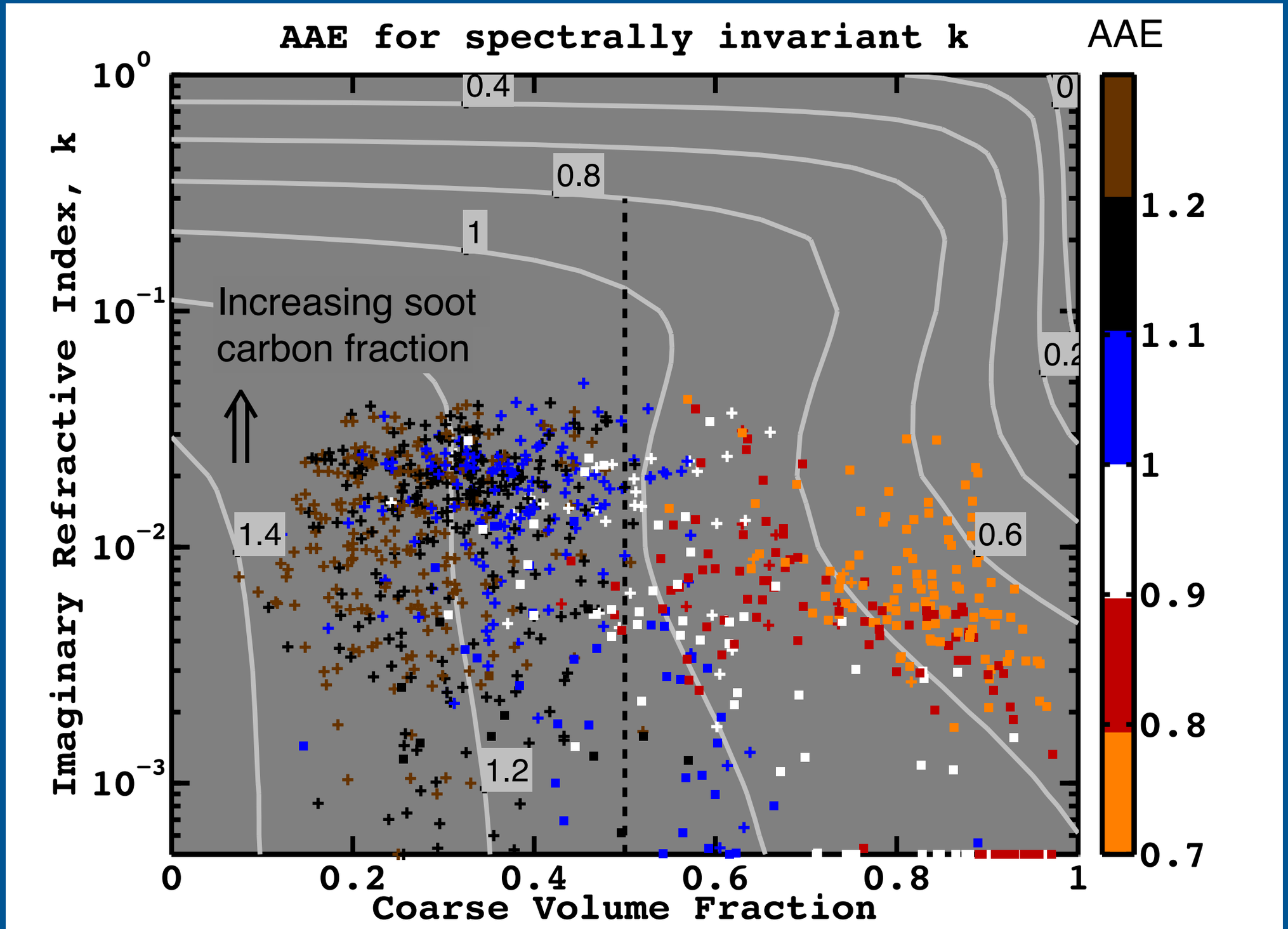

Schuster ACP 2012,
"pure" dust
Chung PNAS 2012,
"pure" dust
Chung PNAS 2012,
"pure" BC
AAE(870–440)
AE(870–440)
4
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
−0.5
0
0.5
1
1.5
2
2.5

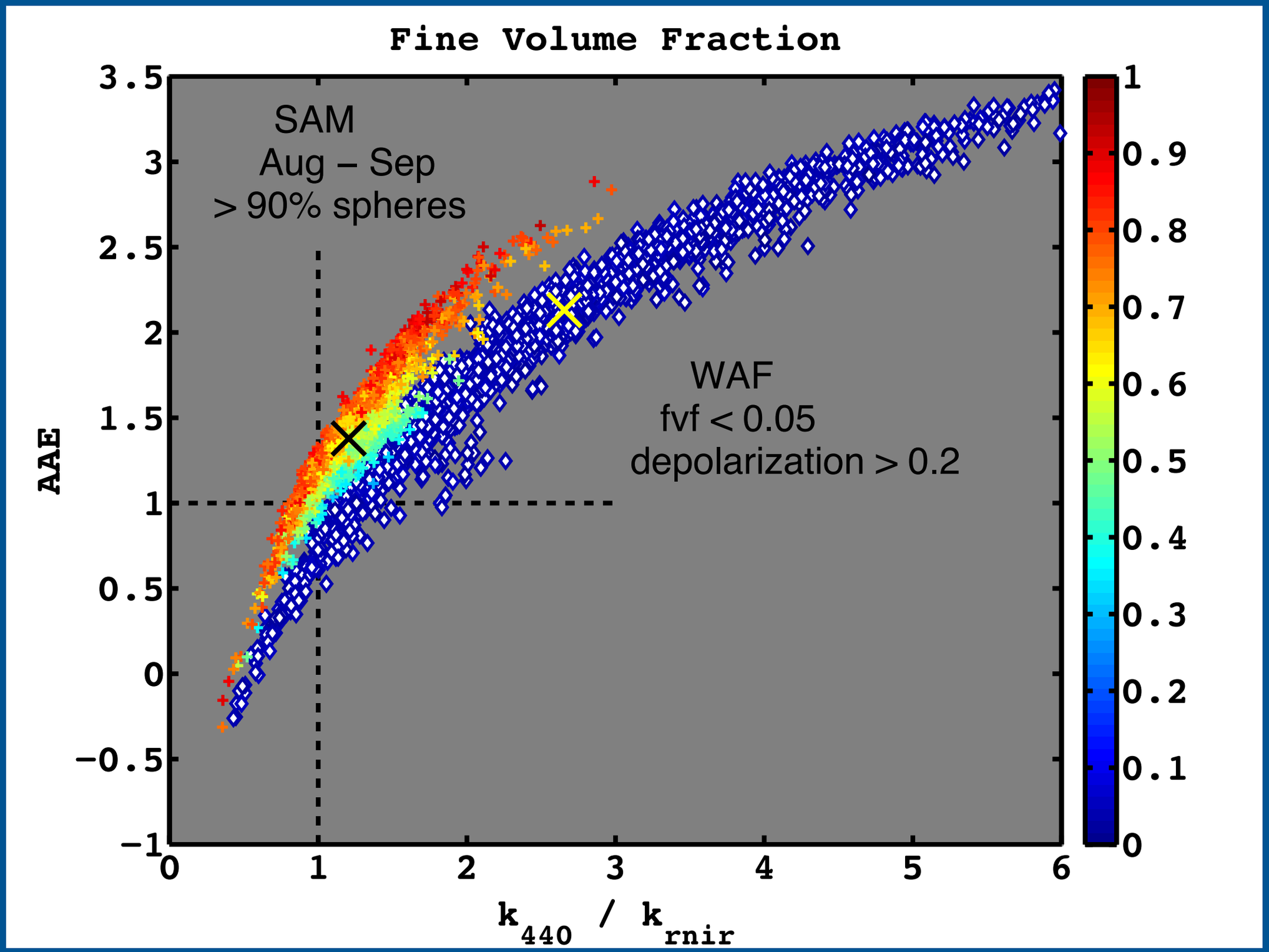


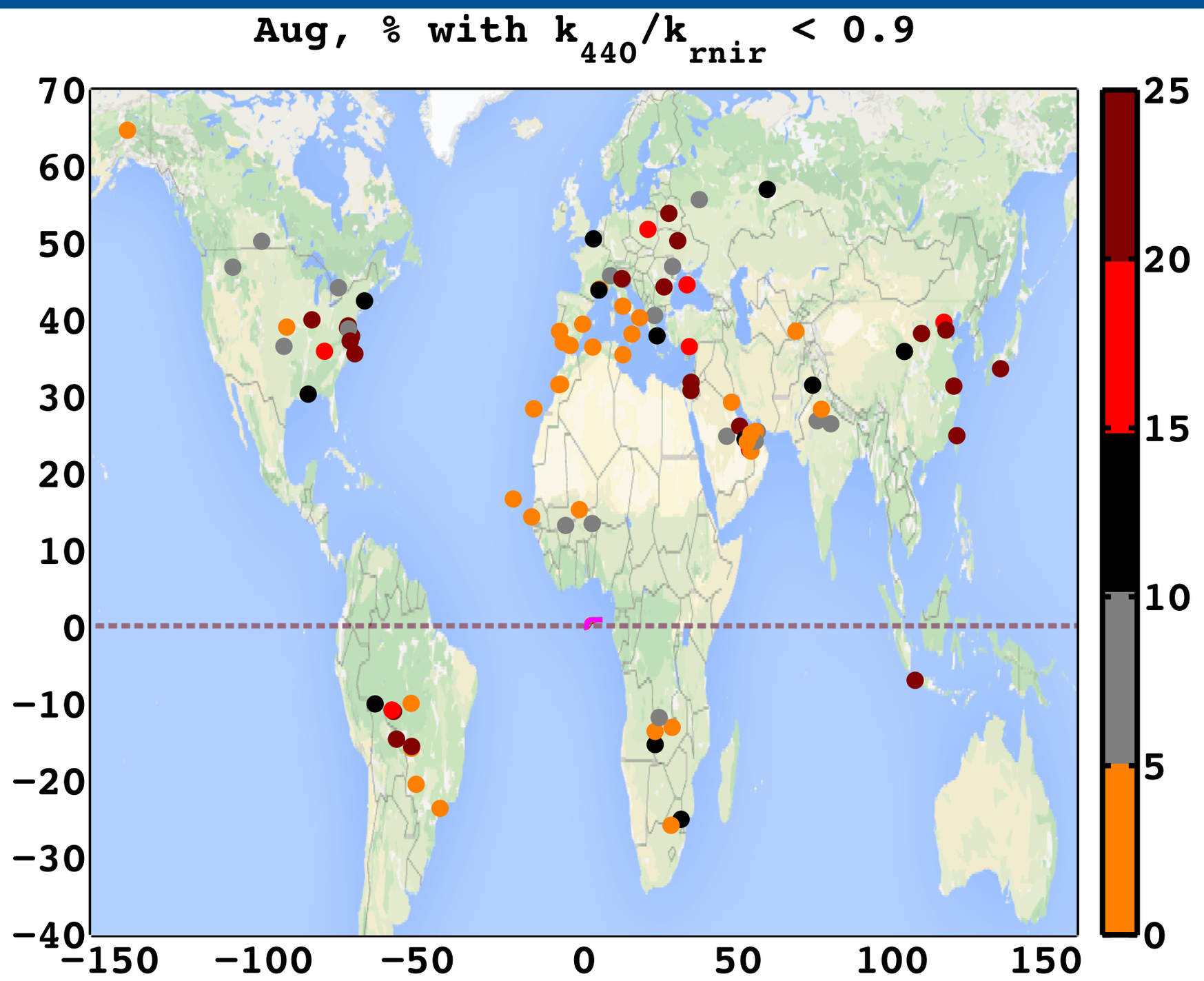
Chung PNAS 2012, "pure" dust

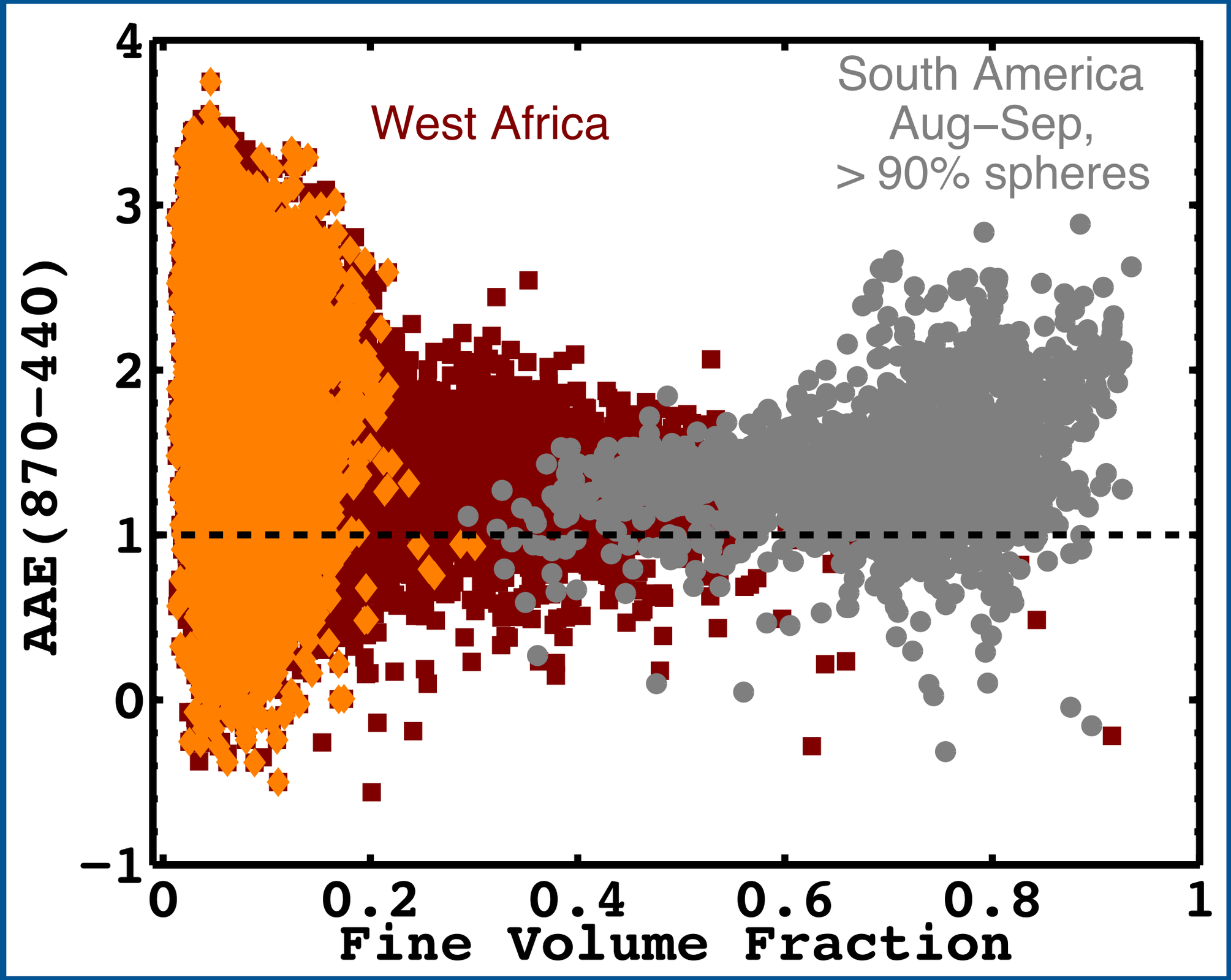
Chung PNAS 2012, "pure" BC

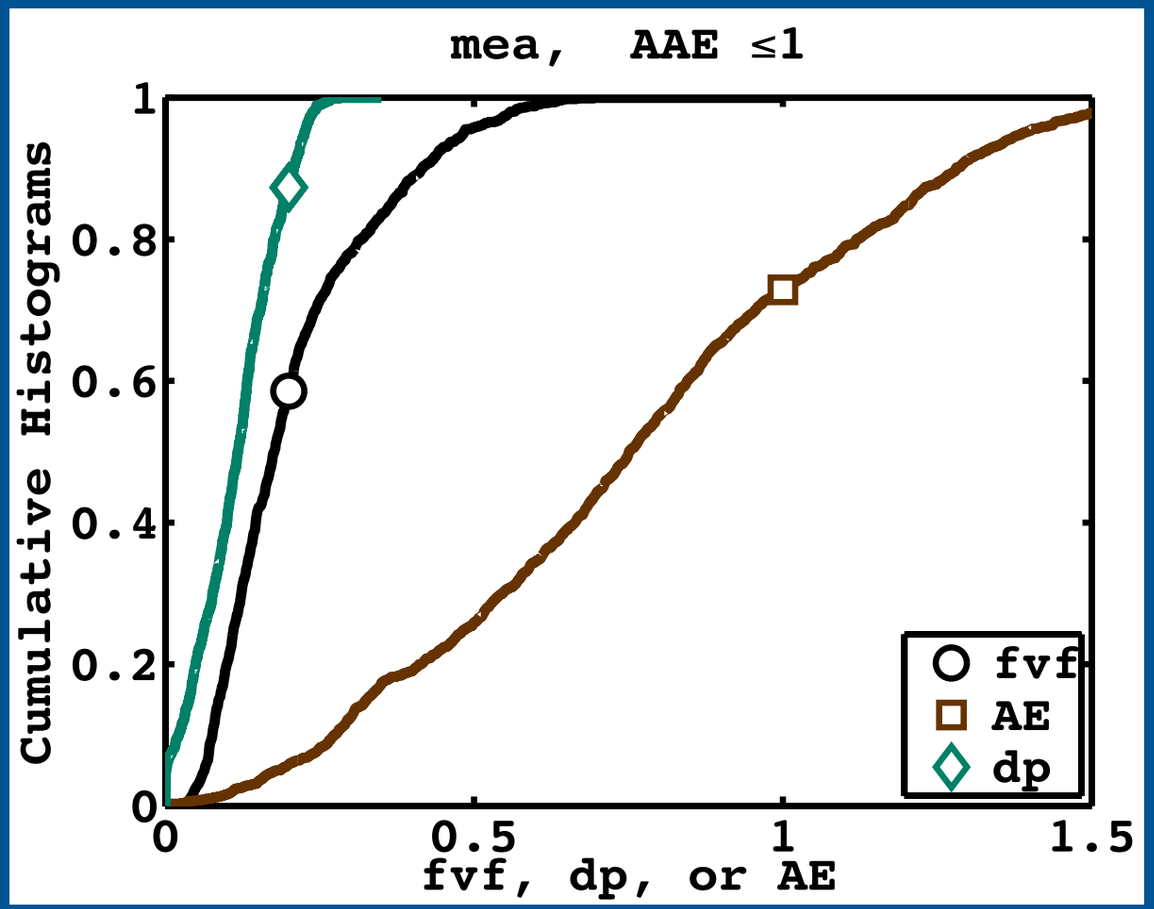

Absorption Angstrom Exponent
Imaginary Refractive Index
Radius, μm
10^0
10^-1
10^-2
10^-3
10^-2
10^-1
10^0
10^1
1
0.6
0.2
0
0.4
0.8
0.9
1.1
1.2
1.4

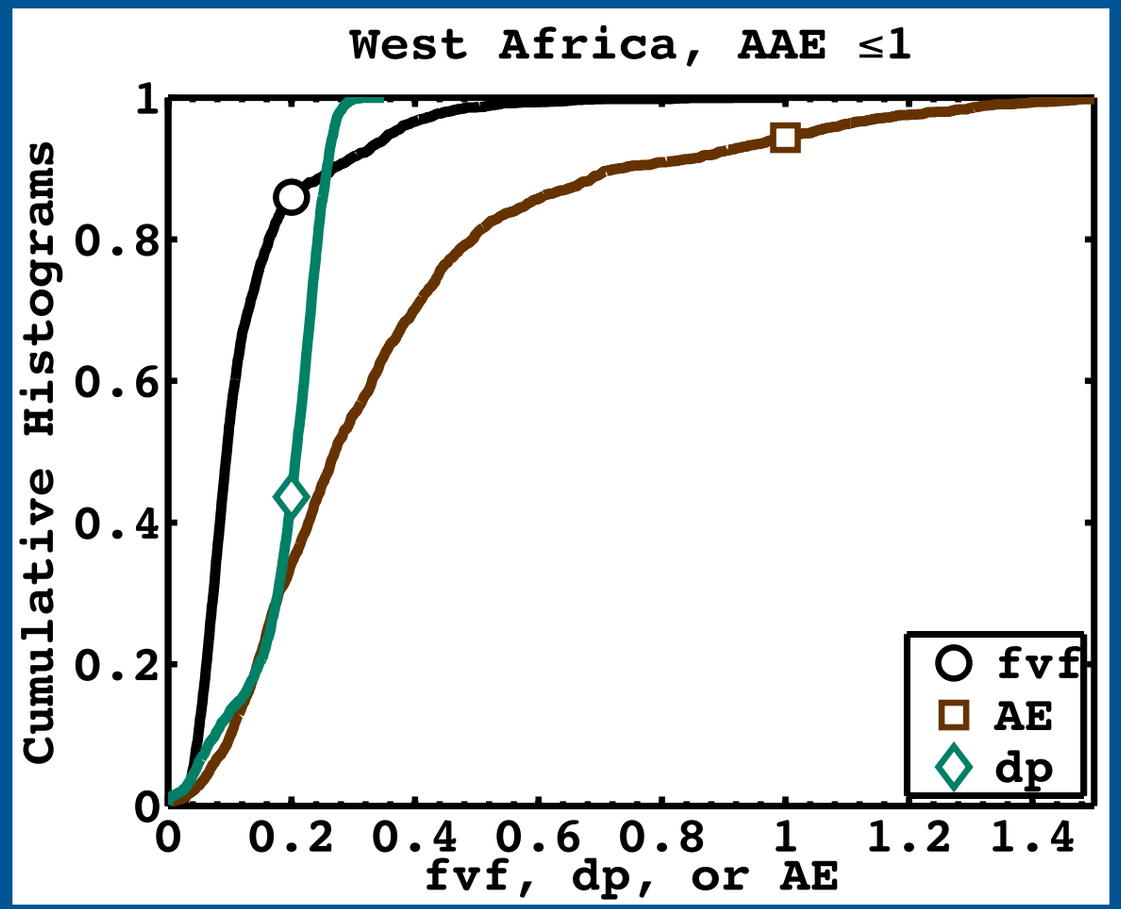

AAE for spectrally invariant k
AAE
Imaginary Refractive Index, k
Coarse Volume Fraction
Increasing soot
carbon fraction
0.4
0.8
1
1.4
1.2
0.6
0
0.2
1.2
1.1
1
0.9
0.8
0.7
10^{0}
10^{-1}
10^{-2}
10^{-3}
0
0.2
0.4
0.6
0.8
1

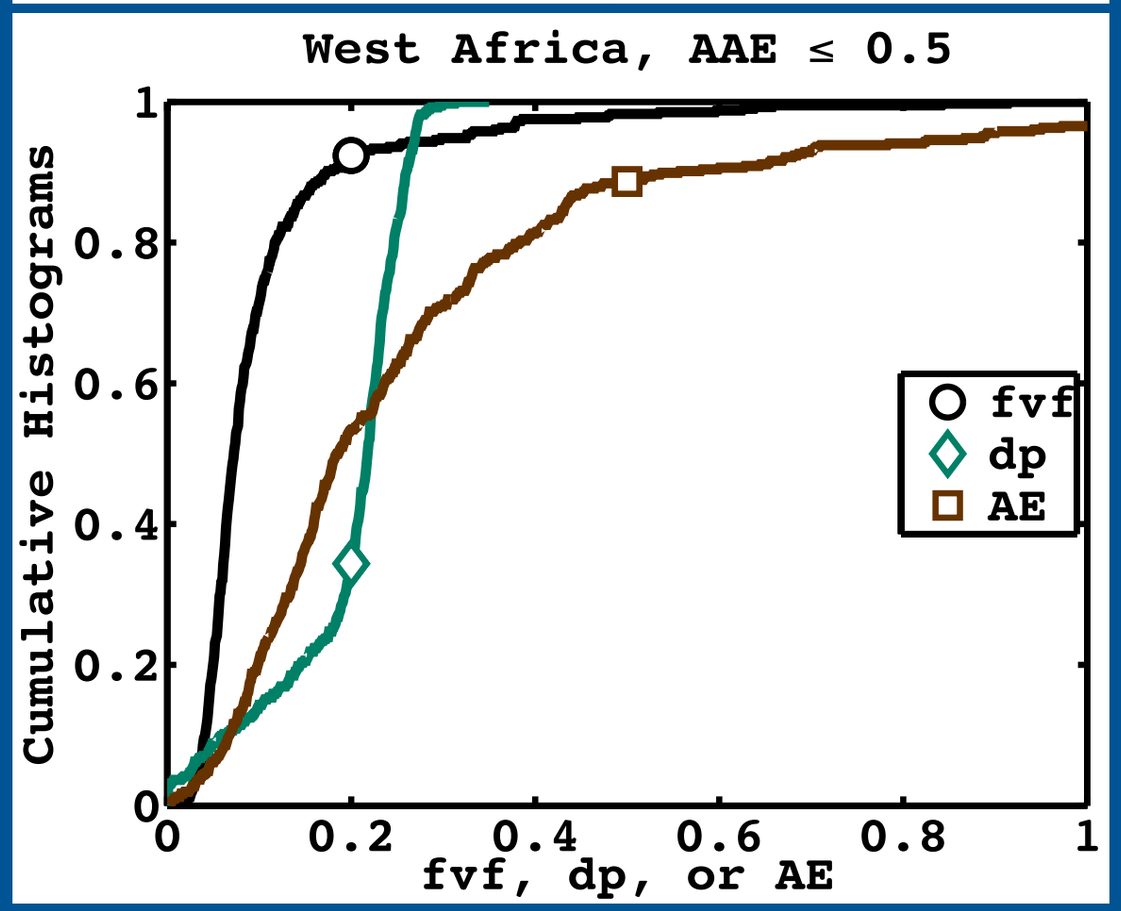

Fine Volume Fraction
SAM
Aug – Sep
> 90% spheres
WAF
fvf < 0.05
depolarization > 0.2
AAE
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
0
1
2
3
4
5
6
k440 / krnir
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

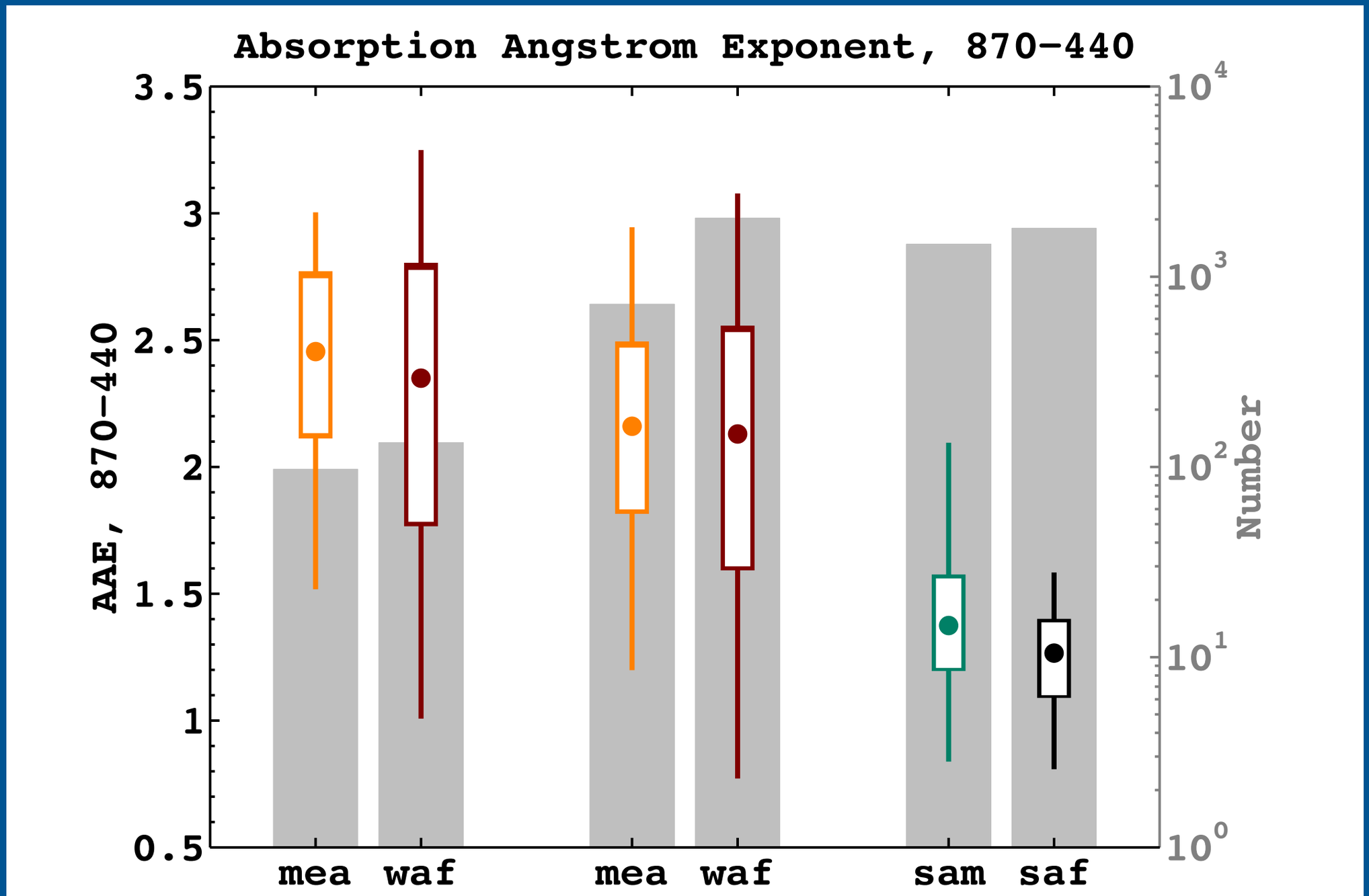

Aug, % with k_{440}/k_{rnir} < 0.9
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−150
−100
−50
0
50
100
150
25
20
15
10
5
0


West Africa
South America
Aug–Sep,
> 90% spheres
AAE(870–440)
4
3
2
1
0
−1
0
0.2
0.4
0.6
0.8
1
Fine Volume Fraction


mea, AAE ≤1
Cumulative Histograms
fvf, dp, or AE
fvf
AE
dp
0
0.2
0.4
0.6
0.8
1
0.5
1.5


West Africa, AAE ≤1
Cumulative Histograms
fvf, dp, or AE
fvf
AE
dp
0
0.2
0.4
0.6
0.8
1
1.2
1.4


West Africa, AAE ≤ 0.5
Cumulative Histograms
fvf, dp, or AE
fvf
dp
AE
0
0.2
0.4
0.6
0.8
1


Absorption Angstrom Exponent, 870–440
AAE, 870–440
3.5
3
2.5
2
1.5
1
0.5
10^4
10^3
10^2
10^1
10^0
Number
mea
waf
mea
waf
sam
saf
fvf < 0.05,
δp ≥ 0.2
Dust, AE < 0

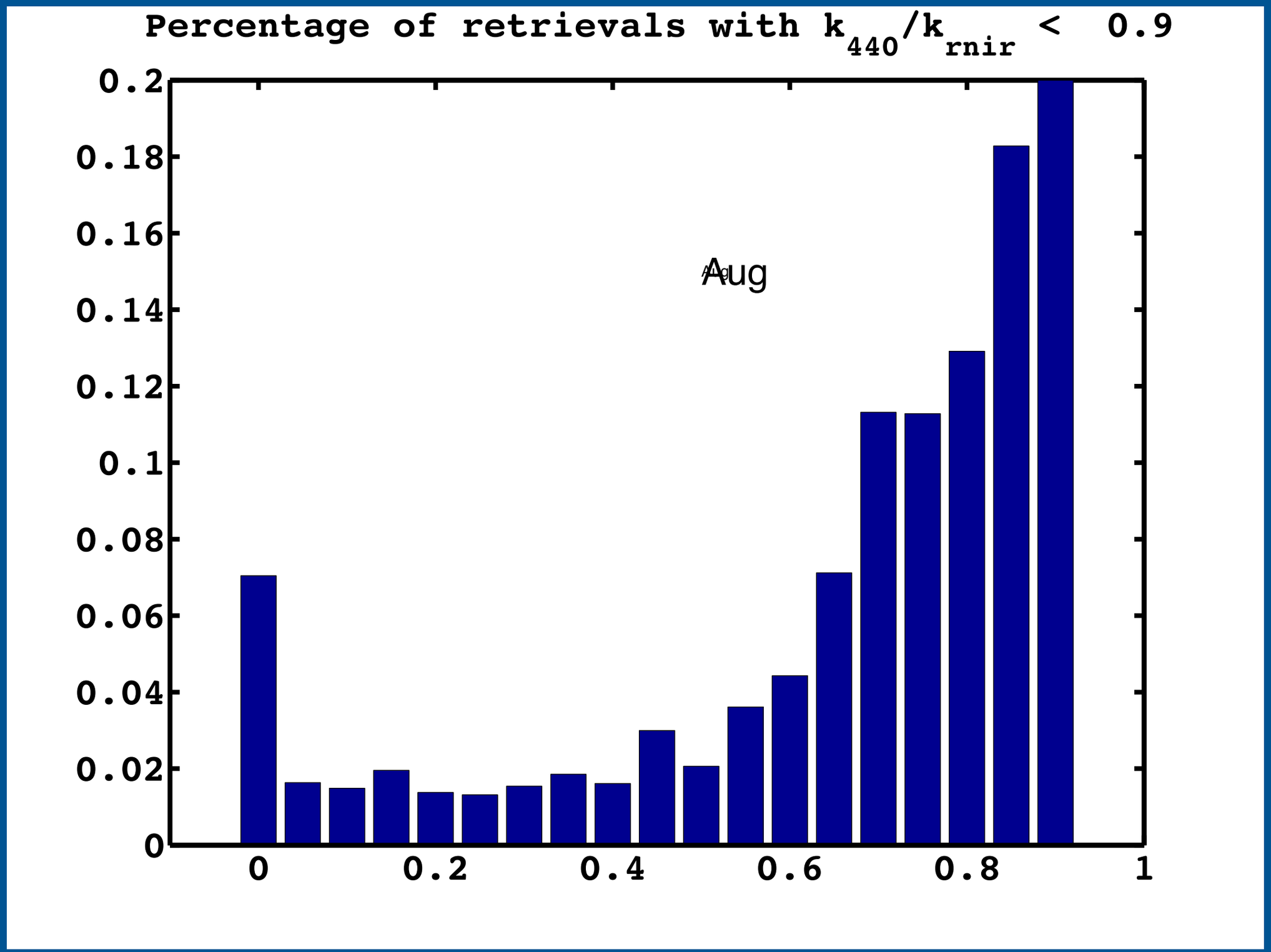

Percentage of retrievals with k440/krnir < 0.9
Aug
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.2
0.4
0.6
0.8
1

Table 1. AERONET sites used in this study.

Dust Sites:

West Africa (waf): Agoufou, Banizoumbou, IER_Cinzana, DMN_Maine_Soroa, Ouagadougou, Djougou, Saada, Capo_Verde, Dahkla, Dakar, Ilorin, Quarzazate, Santa_Cruz_Tenerife, Tamanrasset_INM, Tamanrasset_TMP.

Middle East (mea): Solar_Village, Nes_Ziona, SEDE_BOKER, Dhabi, Hamim.

Biomass Burning Sites

South Africa (saf): Mongu, Skukuza.

South America (sam): Alta_Floresta, Cuiaba, CUIABA-MIRANDA, Abracos_Hill, Balbina, Belterra, SANTA_CRUZ.

Table 2. Percentage of retrievals with $AAE \leq 1$, $k_{440} \leq k_{rnir}$, and $k_{440} \leq k_{rnir}$ when $AAE \leq 1$ at the west Africa (waf), Middle East (mea), south Africa (saf), and South America (sam) sites of Table 1.

Constraint	waf	mea	saf	sam
$AAE < 1$	11	13	16	13
$k_{440} \leq k_{rnir}$	4	6	32	21
$k_{440} \leq k_{rnir}$, given $AAE \leq 1$	39	44	97	94

Table 3. Percentage of retrievals in Figure 5 with $k_{440}/k_{rnir} < 0.8$ (%R); only the sites with %R > 10 are listed here. The site longitudes (Lon), latitudes (Lat), and number of retrievals (#R) are also shown.

Location	Lon	Lat	#R	%R
Djougou	1.6	9.8	18	38.9
Shirahama	135.4	33.7	217	26.7
BONDVILLE	-88.4	40.1	328	22.9
OHP OBSERVATOIRE	5.7	43.9	42	16.7
COVE	-75.7	36.9	291	16.5
UCLA	-118.5	34.1	31	16.1
Cuiaba	-56.0	-15.5	144	16.0
Avignon	4.9	43.9	199	15.6
MD Science Center	-76.6	39.3	408	13.7
IFT-Leipzig	12.4	51.4	69	13.0
Wallops	-75.5	37.9	375	11.5
GSFC	-76.8	39.0	746	10.9
UMBC	-76.7	39.3	65	10.8
Carpentras	5.1	44.1	177	10.7