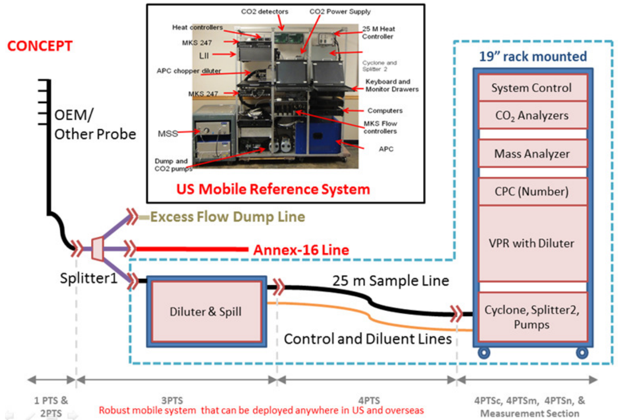

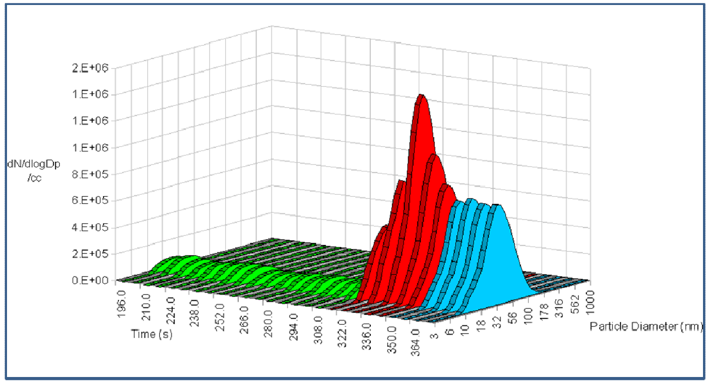

System-Loss Modelling Challenge Data for Gas Turbine Engine Extractive nvPM Sampling Systems

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Engine test size-parameter survey

- 7 campaigns over the last 5 years with extractive PM sampling system equivalent or very similar, to the North American Reference System (NARS)
- Each campaign has multiple data series and included a DMS500.
  - 1 to 4 hours of data per series
- DMS500 size data
  - Fit single or bimodal distributions to downstream data
  - 1 sec averages
- Use these actual engine emissions data to:
  - translate observed downstream size distributions to upstream (EEP) distributions.
  - estimate the **range** of upstream size distribution parameters observed for the range of engines studied.
- Results suitable for testing LLC model.

Overview

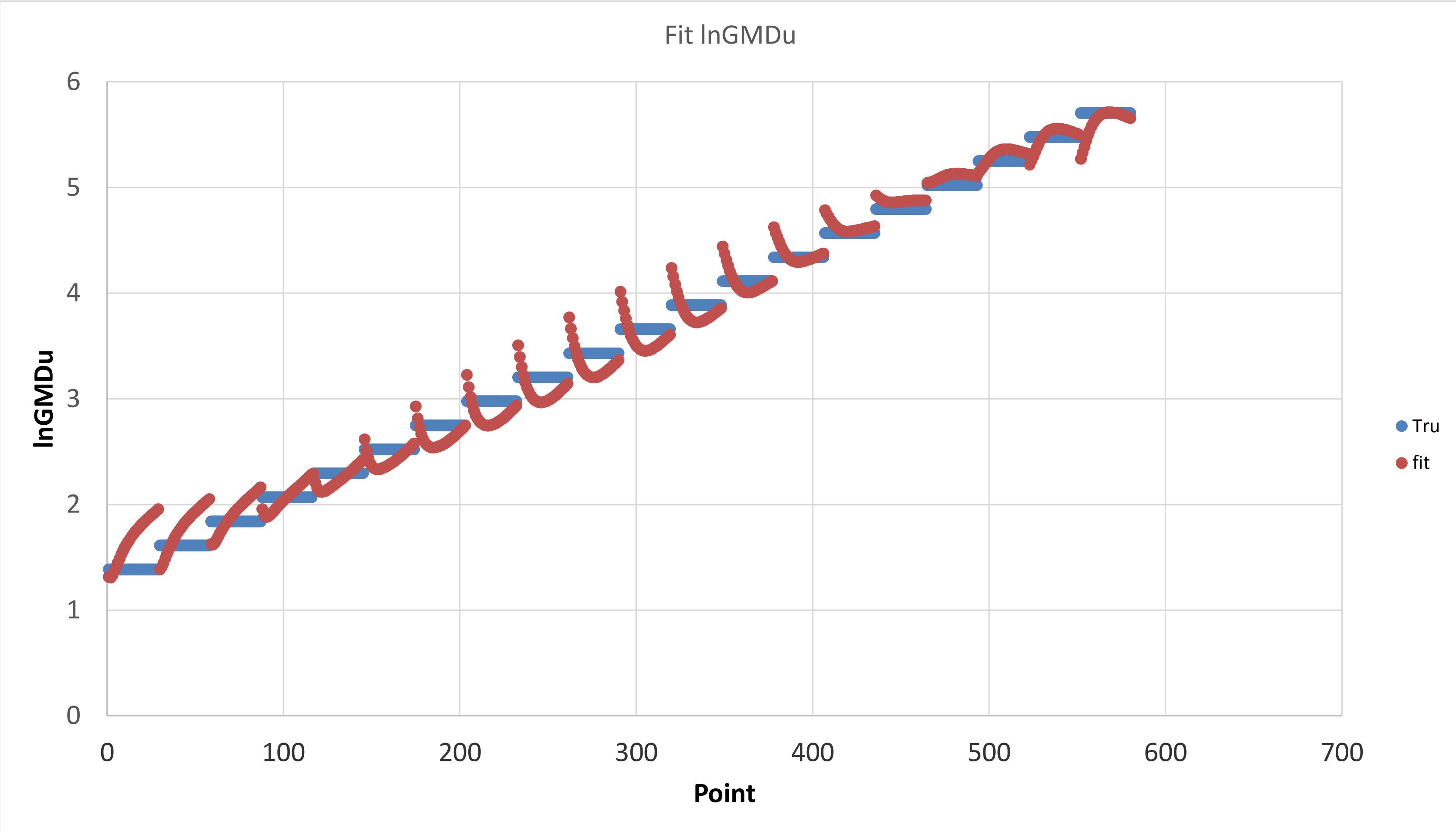
- What we have: Downstream {Dp, dN/dlogDp}
- What we want: Upstream {N_{u1}, GMD_{u1}, GSD_{u1}, N_{u2}, GMD_{u2}, GSD_{u2}}
- What's extracted from each 1 sec data record?
- What's extracted from each data series?
- Results.

Downstream (GMD+GSD) → Upstream lognormal

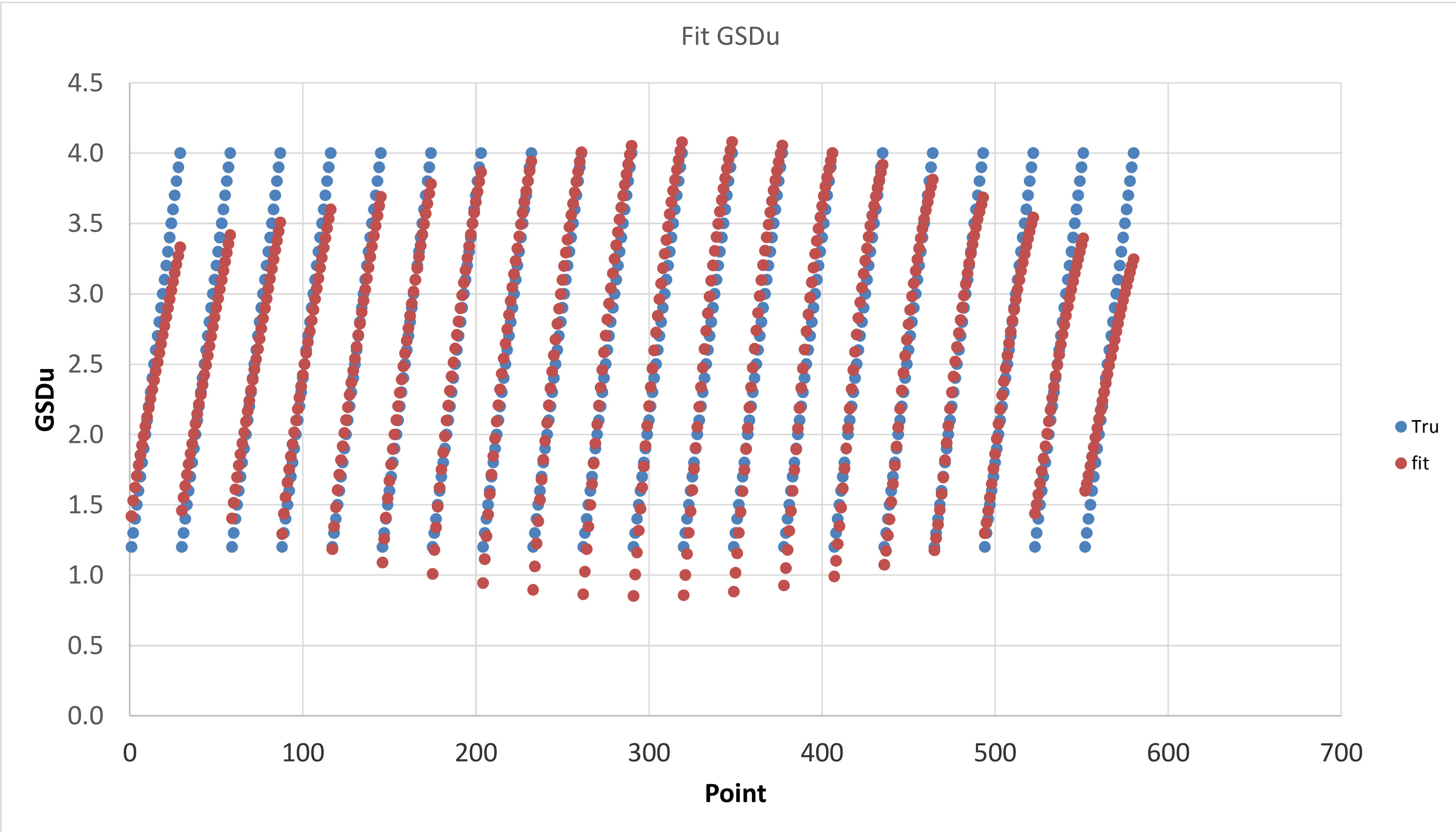
- Define a reasonable range of Engine Exit Plane (EEP) GMDs and GSDs.
  - $1.2 \leq GSD_u \leq 4$ pick 30 typical values
  - $4 \leq GMD_u \leq 300$ pick 20 typical values
  - Result 600 GMD GSD pairs: j=1,2,…600
- For each pair j (GMD_u, GSD_u)
  - First calculate EEP lognormal
  - Then calculate the downstream size distributions using NARS pen_{DMS}.
  - Then calculate downstream GMD_d and GSD_d
  - Result $\{GMD_{uj}, GSD_{uj}, GMD_{dj}, GSD_{dj}\}$ j=1,2,…600
- Do a linear least squares multifunction fit
  - $GMD_u = \exp[\sum b_i * f_i(\ln GMDd, GSDd)]$
  - $GSD_u = \sum a_i * f_i(\ln GMDd, GSDd)$

i	a	b	f
1	-0.7010	2.1315	1
2	-0.8520	3.4067	lnGMDd
3	2.4495	-3.7881	GSDd
4	-0.9187	1.5849	GSDd*lnGMDd
5	0.6019	-0.8930	lnGMDd^2
6	0.2326	0.1005	GSDd^2

GMDu Fit function



GSDu Fit function



Processing a downstream mode to get Upstream information

What we start with - $\{N_d, GMD_d, GSD_d\}$

$GMD_d, GSD_d \rightarrow GMD_u, GSD_u, snu/N_u$

where snu=dN/dlogx

$N_d = N_u \sum_i \boldsymbol{\Delta_i} (snu_i/N_u) pen_{dms,i}$

$N_u = N_d / \sum_i \boldsymbol{\Delta_i} (snu_i/N_u) pen_{dms,i}$

$N_u = N_u \sum_i \boldsymbol{\Delta_i} (snu_i/N_u)$ with 10nm cut off

$M_u = (\pi\rho/6) N_u GMD_u^3 \exp(4.5 \ln(GSD_u)^2)$

What we calculate - $\{N_u, N_u, GMD_u, GSD_u, M_u\}$

Process engine test data; For each 1 sec average:

• Nmode	1 for single mode, 2 for bimodal
• GMD1_Si	GMD for single mode case
• GSD1_Si	GSD for single mode case
• Xu	Upstream $(M/N)^{1/3}$**
• GMD1_Bi	GMD for 1st mode of a bimodal distr.
• GSD1_Bi	GSD for 1st mode of a bimodal distr.
• GMD2_Bi	GMD for 2nd mode of a bimodal distr.
• GSD2_Bi	GSD for 2nd mode of a bimodal distr.
• GMDu_tot	GMD for the total bimodal size distr.
• GSDu_tot	GSD for the total bimodal size distr.
• Nu1/Nu2_Bi	Conc ratio of mode 1 / mode 2, for bimodal case.
• Mu2/Mu1_Bi	Mass in mode 2/Mass in mode 1, for bimodal case.

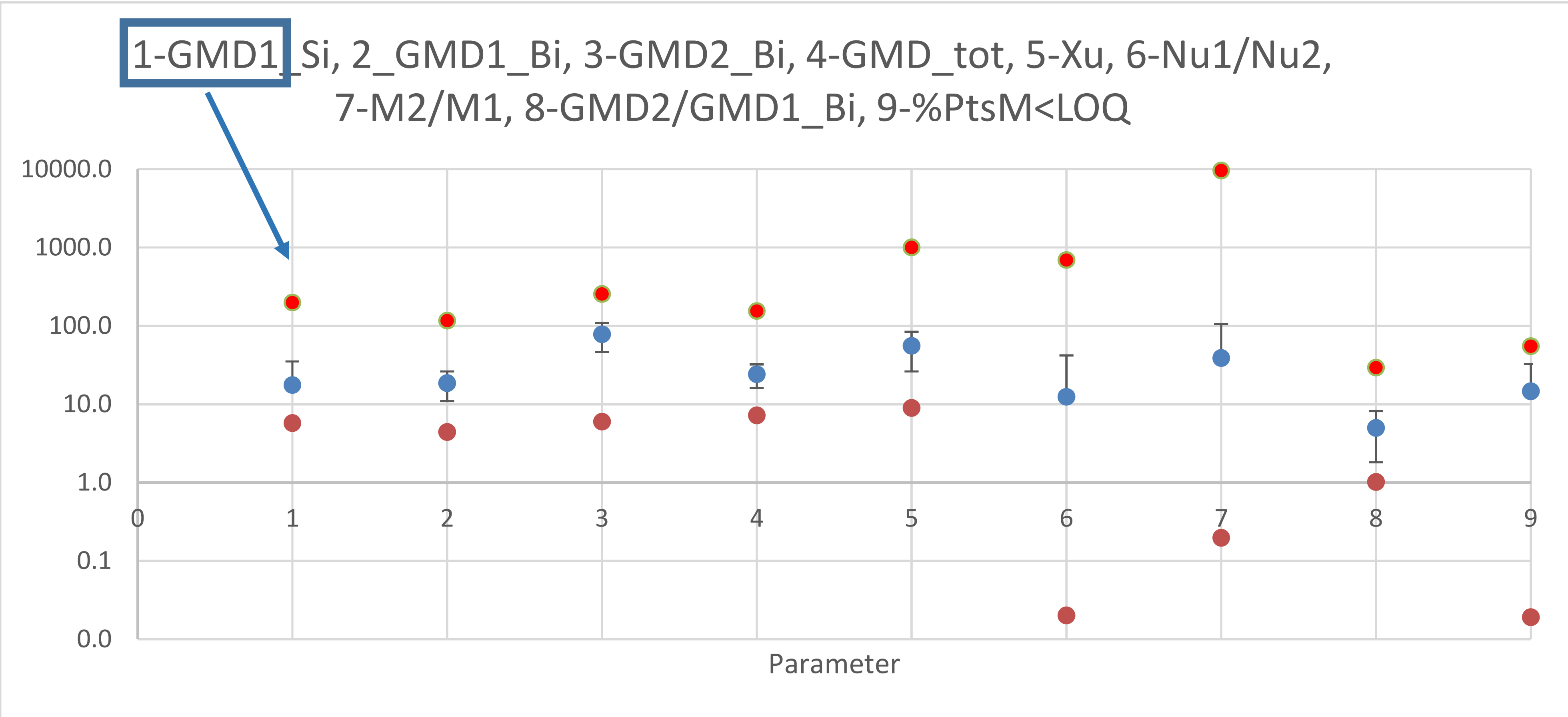
**Size parameter – proportional to estimated mean diameter

For an engine test series determine

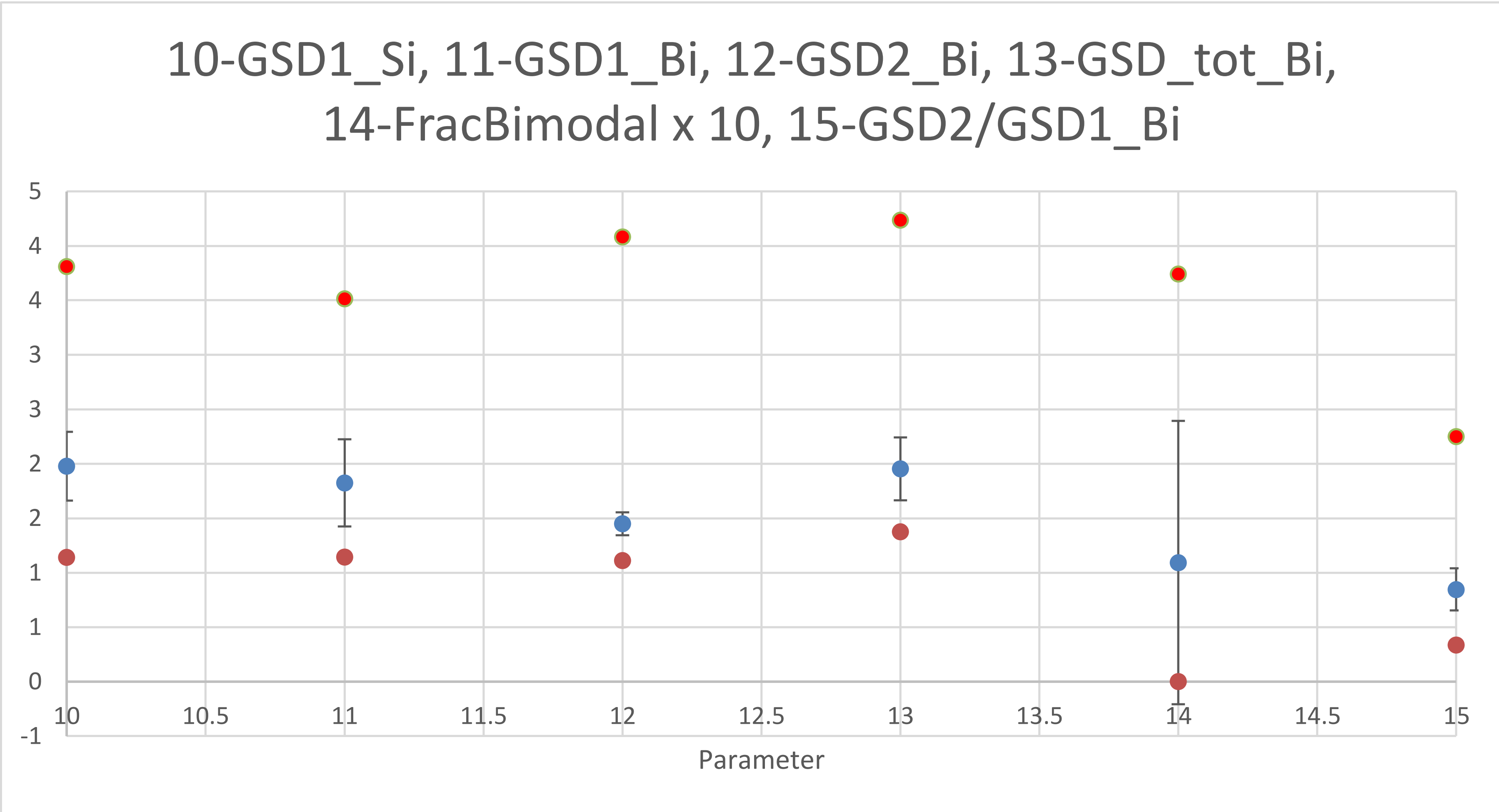
(typical series could be 2 hours of 1 sec average data)

- Fraction of Bimodal distributions observed
- %PtsM<LOQ   Percentage of points with measured mass less than LOQ
- Statistical analysis of 1 sec data parameters:
  - Average,
  - Standard Deviations
  - 1-th percentile. (%Tile1) - the value of the parameter such that 1% of observed parameter values are below this value.
  - (reasonable value to use for the minimum observed parameter value).
  - 99.5-th percentile. (%Tile99.5) - the value of the parameter such that 99.5% of observed parameter values are below this value.
  - (reasonable value to use for the maximum observed parameter value).

Results Group 1



Results Group 2



Conclusions

- **Bimodal size distributions are found in a significant portion of samples, 11% (13%).**
- **The range of GMD and GSD for the 1st mode doesn't change significantly if a 2nd mode is observed.**
- **When a 2nd mode is observed it's GMD is larger than the 1st by ~ factor of 5; it's width is narrower by ~15% (12%).**
- **A significant portion of the mass measurements, 14%, fall below the current LOQ=3 μg/m^3. Newer engines are expected to have lower mass concentrations.**
- **With respect to LLC modelling Xu's mean value (55nm) is well above the ARP sample train cut at 10nm, but the minimum observed value (9nm) is below the cut.**

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