Update on HIWC Activities at U Illinois: Exploring Controls of Particle Size Distributions

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[2]NCAR, Boulder, CO

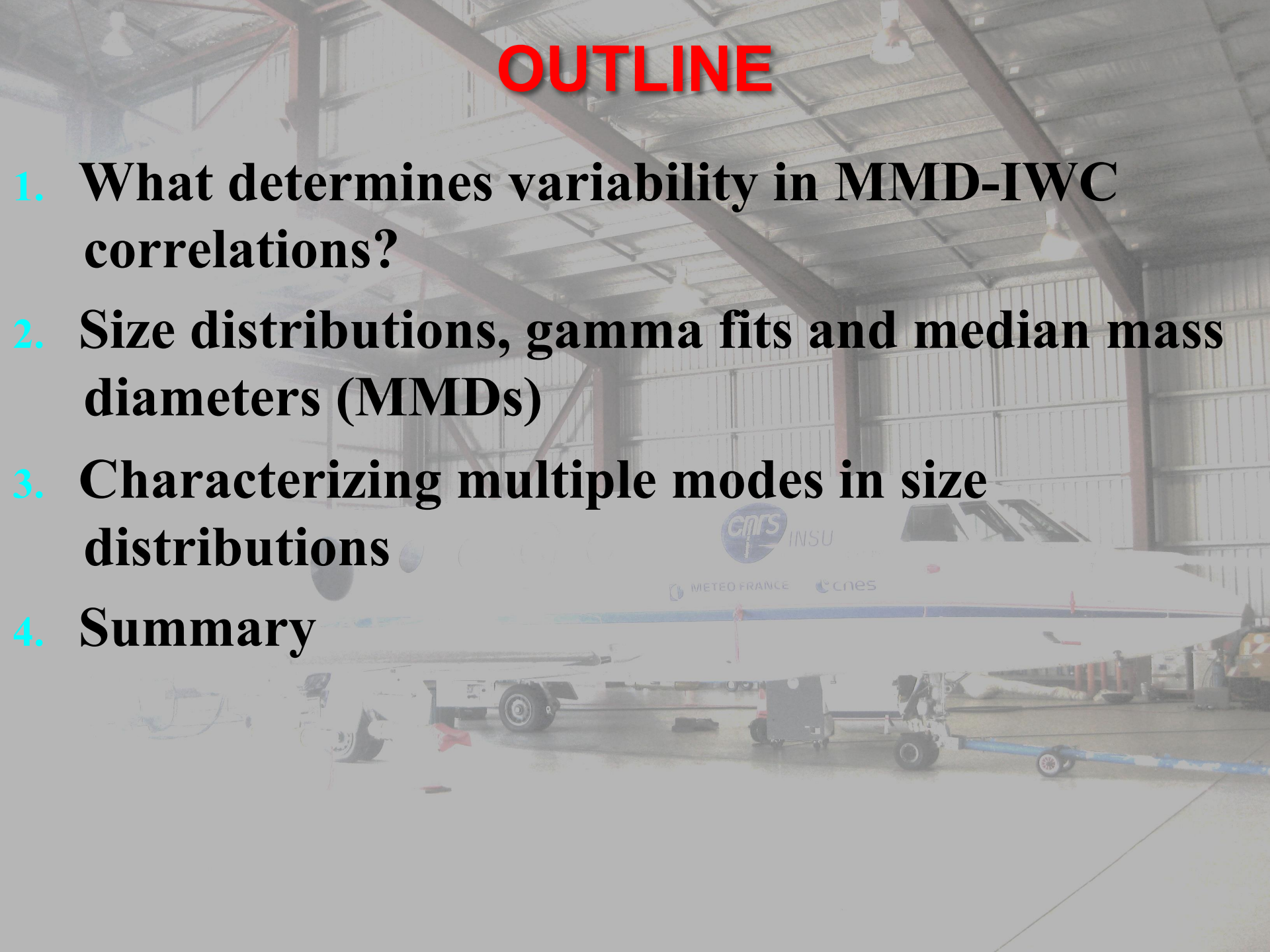
[3]U Blaise Pascal, Clermont

[4]Environment Canada, Downsview, ON

[5]Met Analytics, Toronto, ON

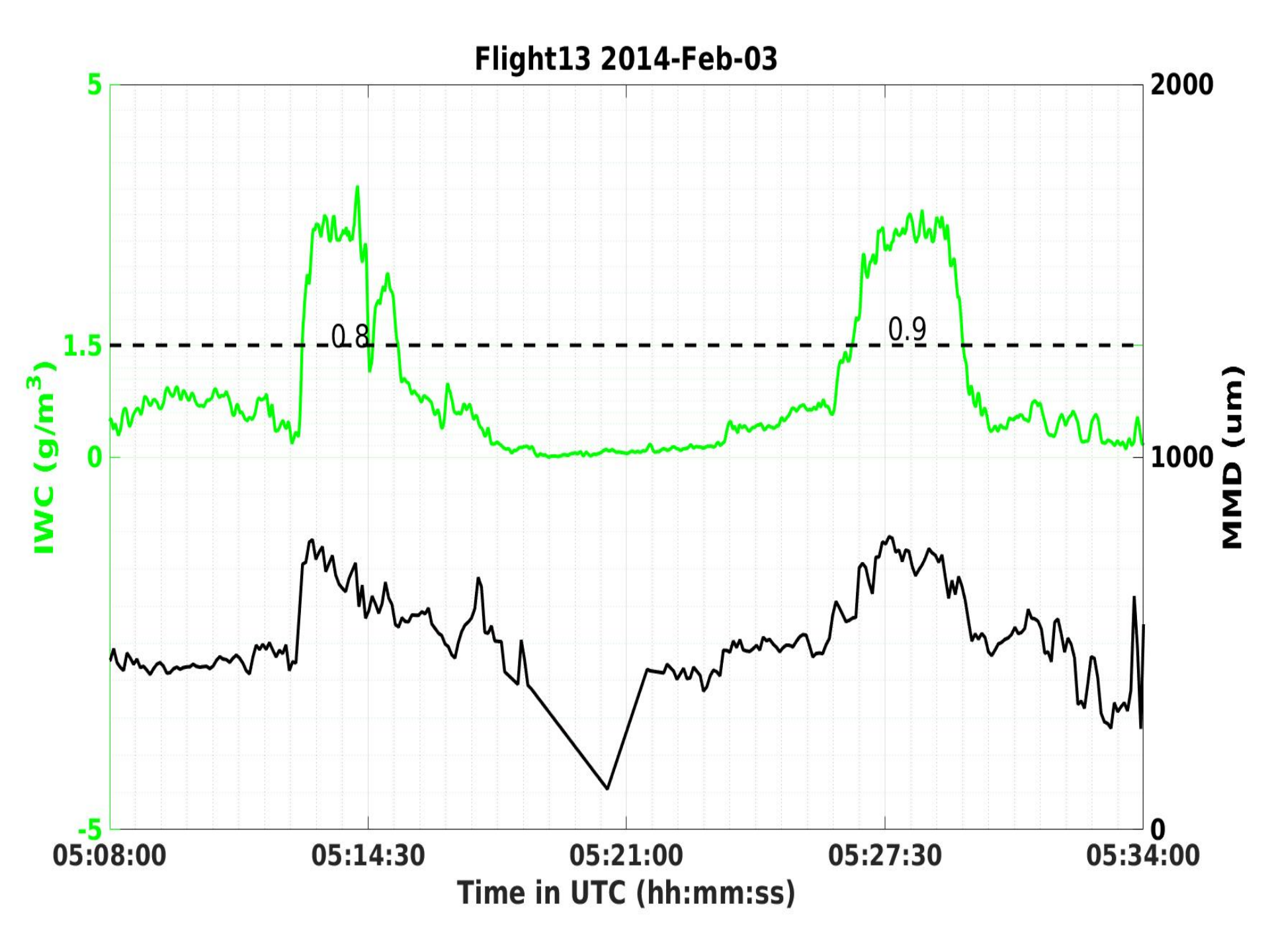
OUTLINE

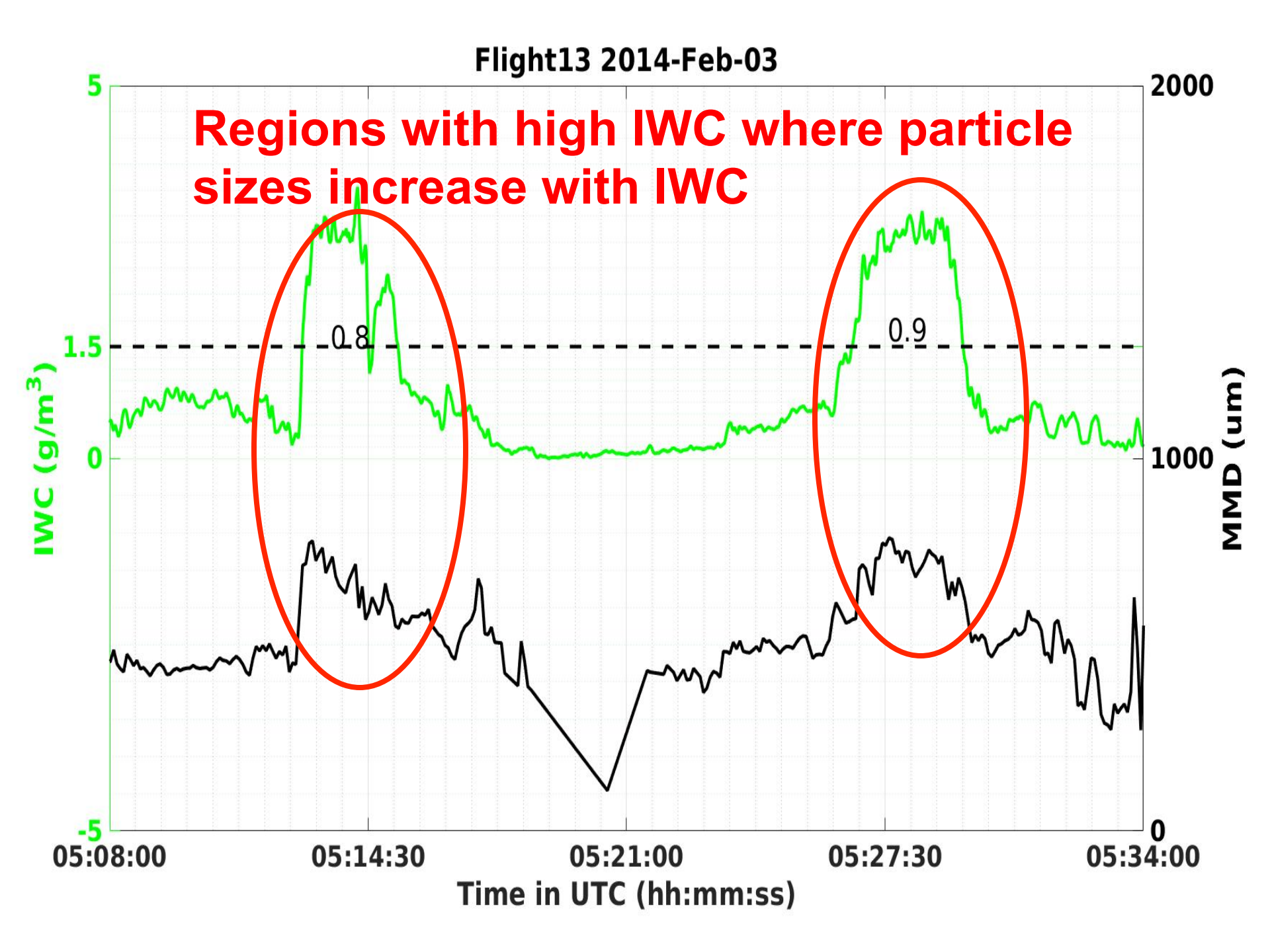
1. What determines variability in MMD-IWC correlations?
2. Size distributions, gamma fits and median mass diameters (MMDs)
3. Characterizing multiple modes in size distributions
4. Summary

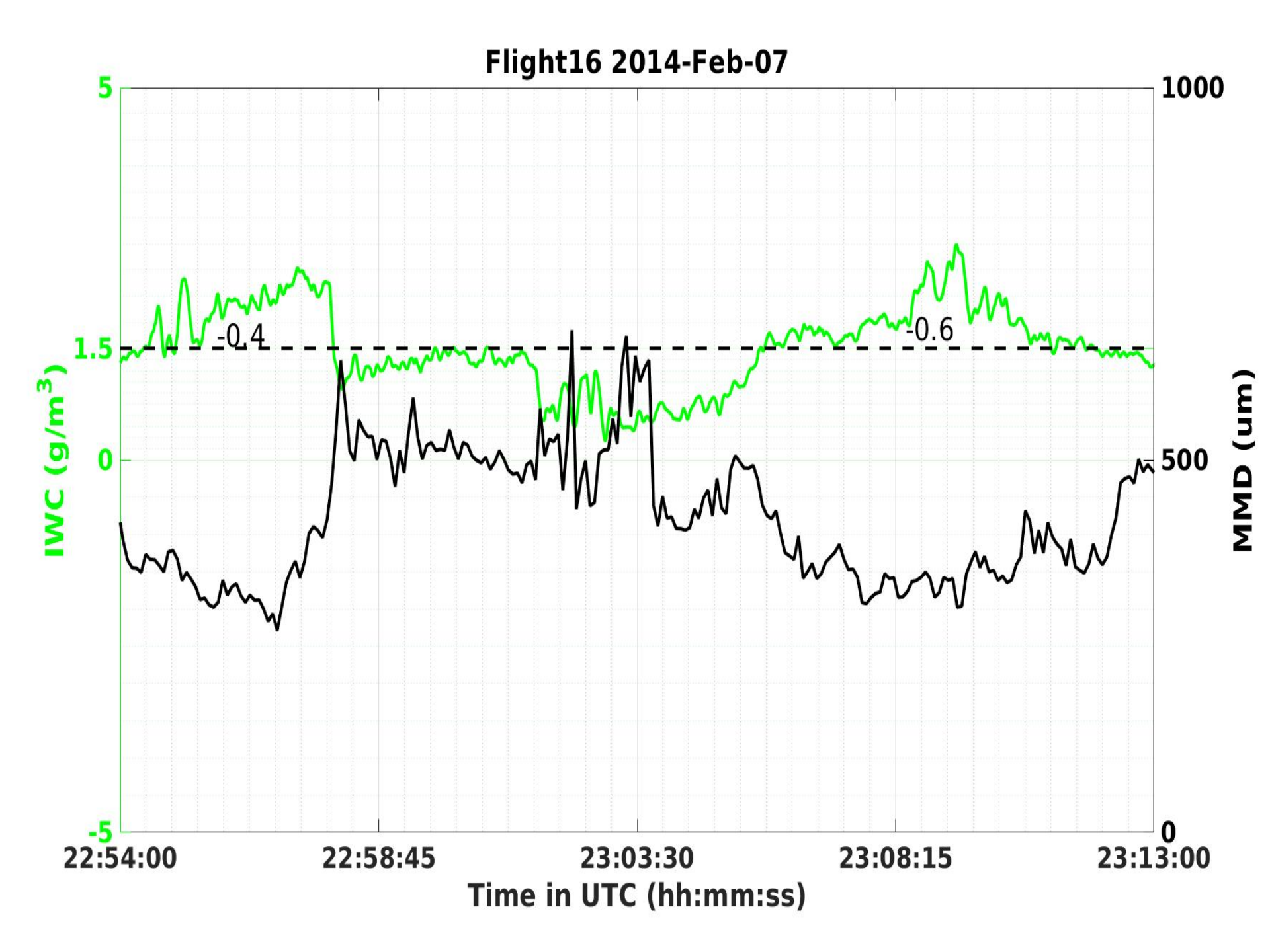


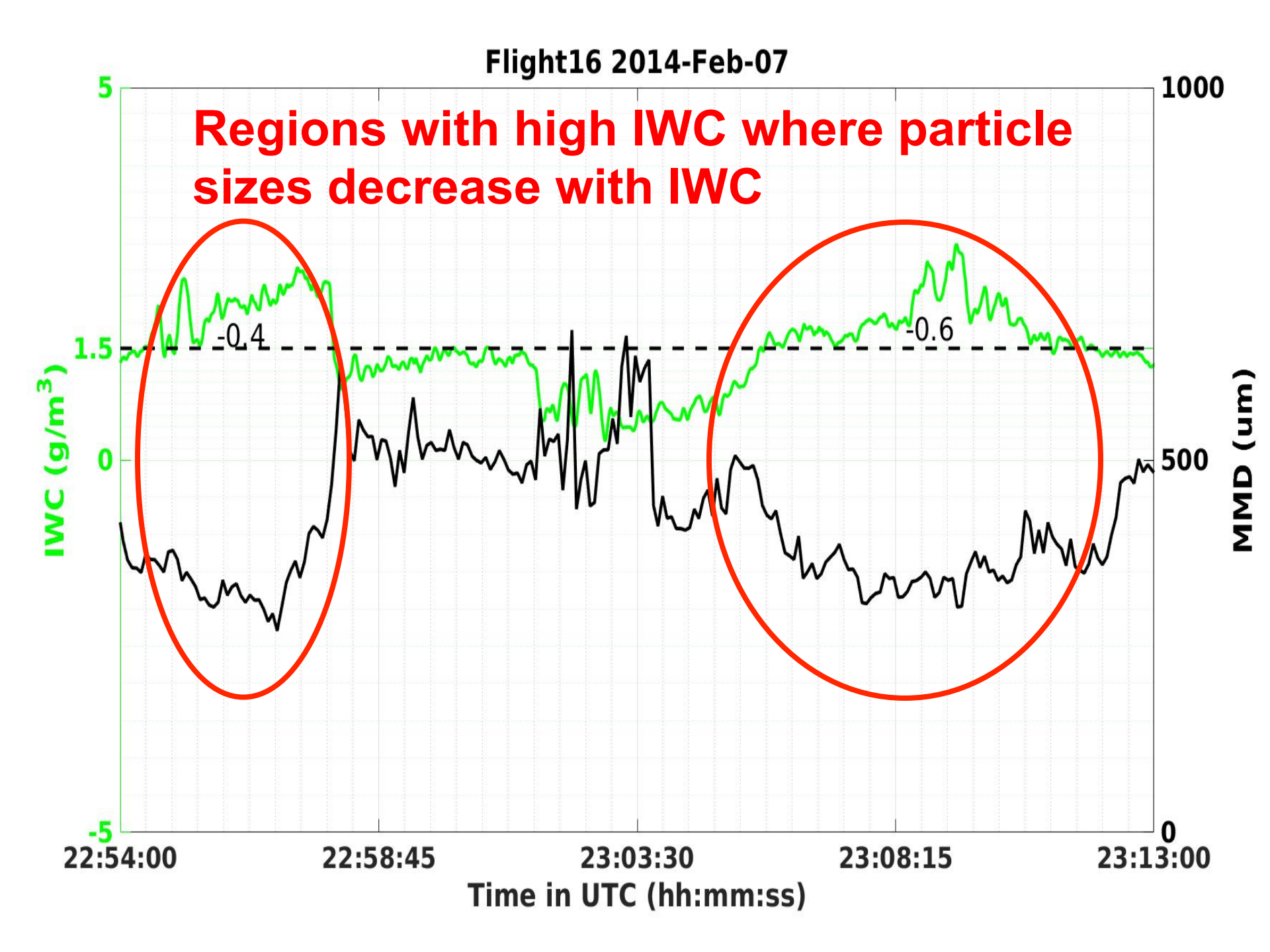
Publication Update

- 28: Zhu, S., G.M. McFarquhar, W.Wu, A. Schwarzenboeck, A.V. Korolev, J.W. Strapp and D. Leroy, 2017: The dependence of ice cloud size distributions represented as gamma functions on meteorological and cloud conditions: Results from the High Ice Water Content Campaign. J. Atmos. Sci., planned submission
- 29: Um, J., G.M. McFarquhar, S. Zhu, A. Schwarzenboeck, A.V. Korolev, J. W. Strapp, and D. Leroy, 2017: Single-scattering properties derive from multi-modal size distributions measured during HAIC/HIWC. To submit to JAS 2017
- 85:McFarquhar, G.M., et al., 2016: Processing of Cloud In-Situ Data Collected by Bulk Water, Scattering and Imaging Probes: Fundamentals, Uncertainties and Efforts towards Consistency. Amer. Meteor. Soc. Monographs.
- 86: Um, J., et al., 2017: The radiative consequences of frozen droplets and particles in the upper regions of convective storms, JAS, In preparation
- Cancel 30; No updates on conference list

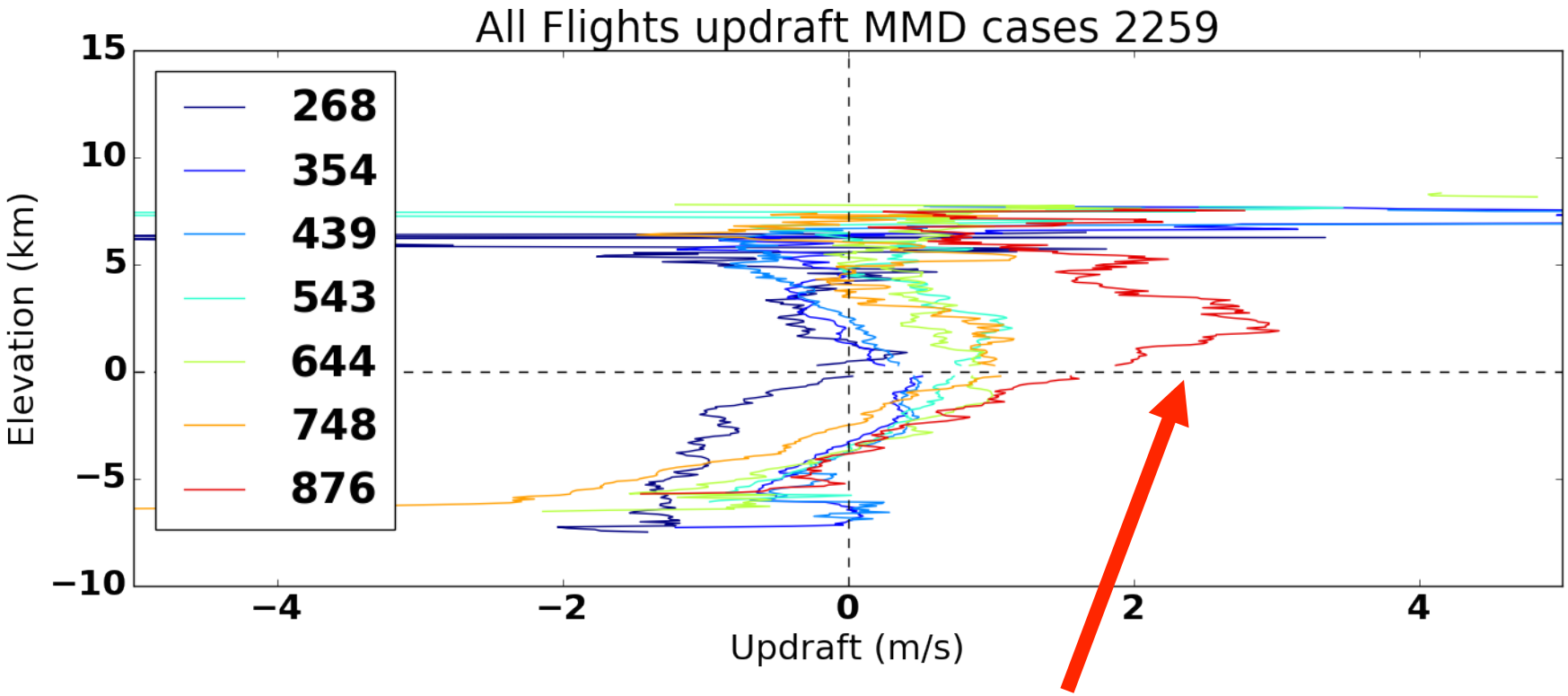

Flight13 2014-Feb-03
5
1.5
0
-5
IWC (g/m3)
2000
1000
0
MMD (um)
0.8
0.9
05:08:00
05:14:30
05:21:00
05:27:30
05:34:00
Time in UTC (hh:mm:ss)


Flight13 2014-Feb-03
Regions with high IWC where particle sizes increase with IWC
0.8
0.9
IWC (g/m3)
MMD (um)
5
1.5
0
-5
2000
1000
0
05:08:00
05:14:30
05:21:00
05:27:30
05:34:00
Time in UTC (hh:mm:ss)


Flight16 2014-Feb-07
5
1.5
0
-5
1000
500
0
IWC (g/m3)
MMD (um)
-0.4
-0.6
22:54:00
22:58:45
23:03:30
23:08:15
23:13:00
Time in UTC (hh:mm:ss)

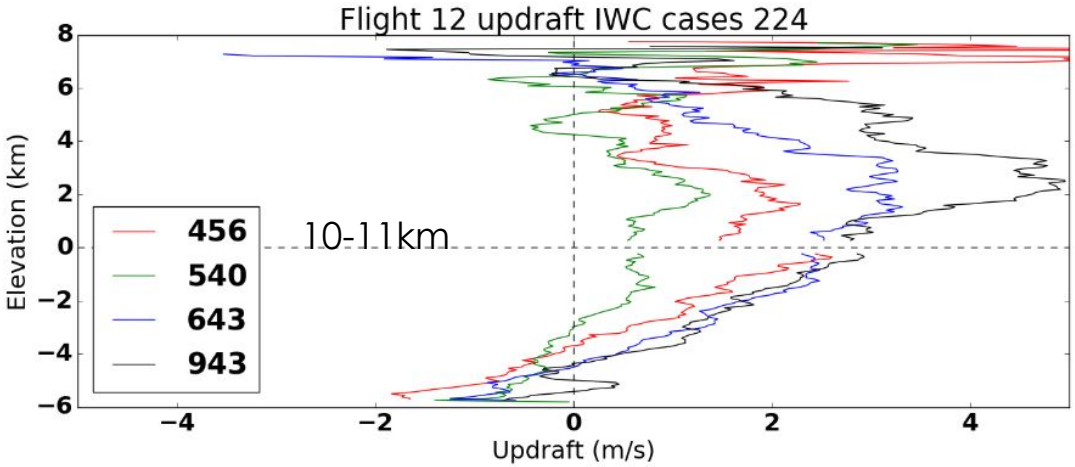

Flight16 2014-Feb-07
Regions with high IWC where particle sizes decrease with IWC
-0.4
-0.6
IWC (g/m3)
MMD (um)
5
1.5
0
-5
1000
500
0
22:54:00
22:58:45
23:03:30
23:08:15
23:13:00
Time in UTC (hh:mm:ss)

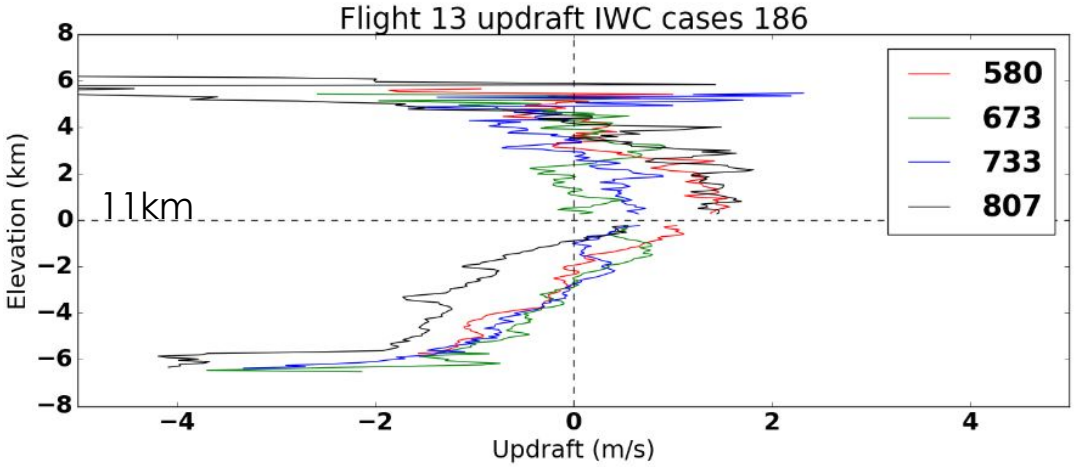
Vertical wind profile

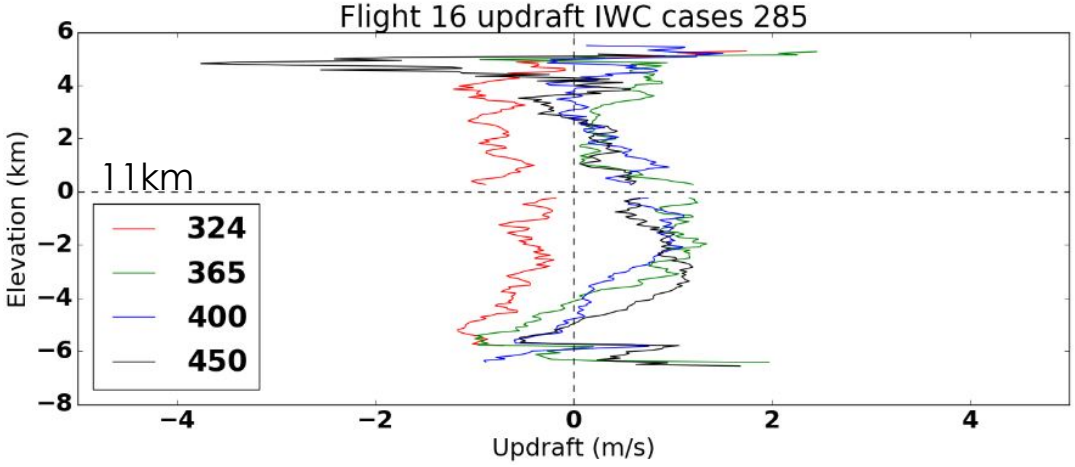


Vertical wind profile

- Convection weakens in the afternoon in Flight 13.
- Maximum updraft location indicates the height of anvil.
- Flight 16 was sampling over oceanic convection has less strength and lower anvil.

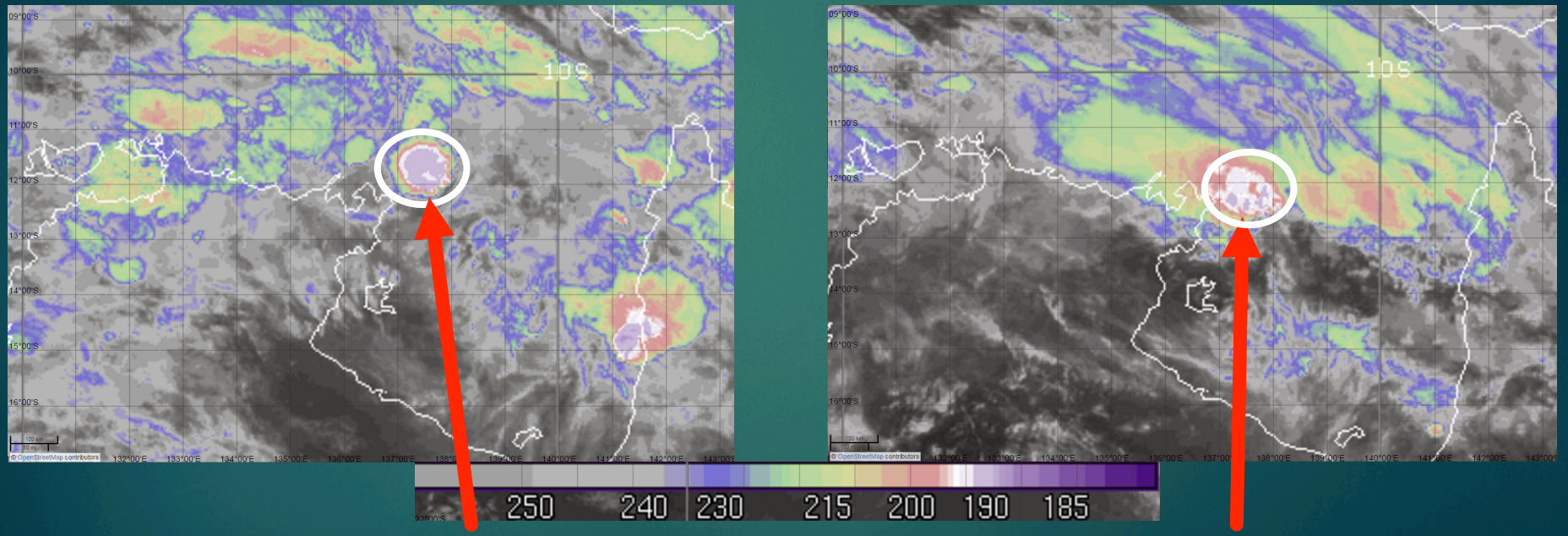






MMD-IWC Correlations

- Lifecycle of convective system.
- Quantified by maximum time cloud top remains above a brightness temperature (BT) threshold.

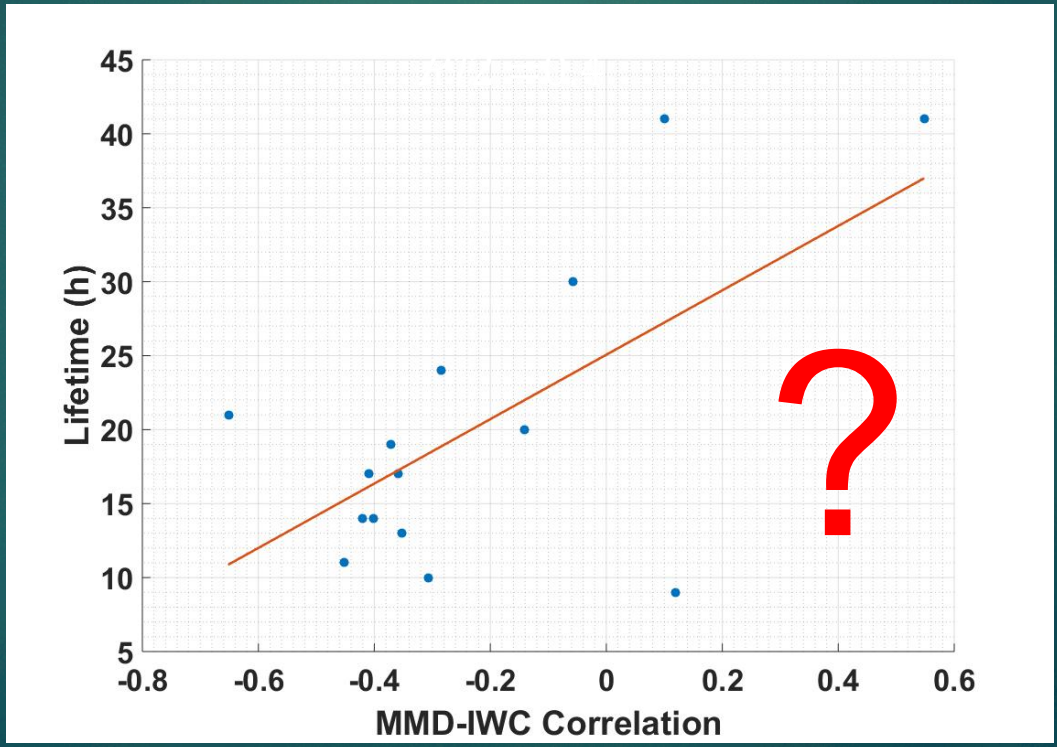


2014-1-29 16:00 ------ The first time T_b < 195 K

2014-1-30 01:00 ------ The last time before all T_b > 195 K

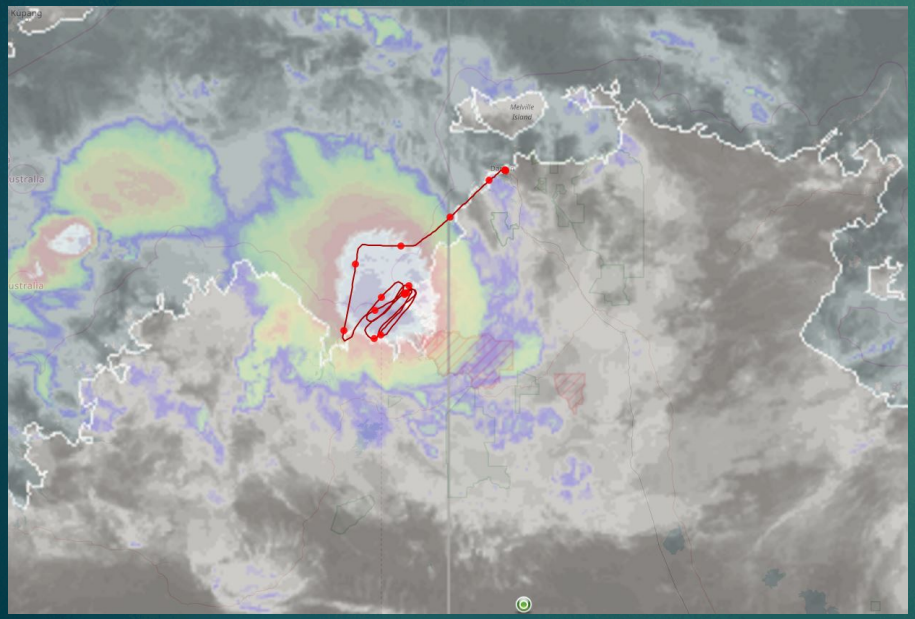
MMD-IWC Correlations

- Weak correlation between convective system age and the MMD-IWC correlation.

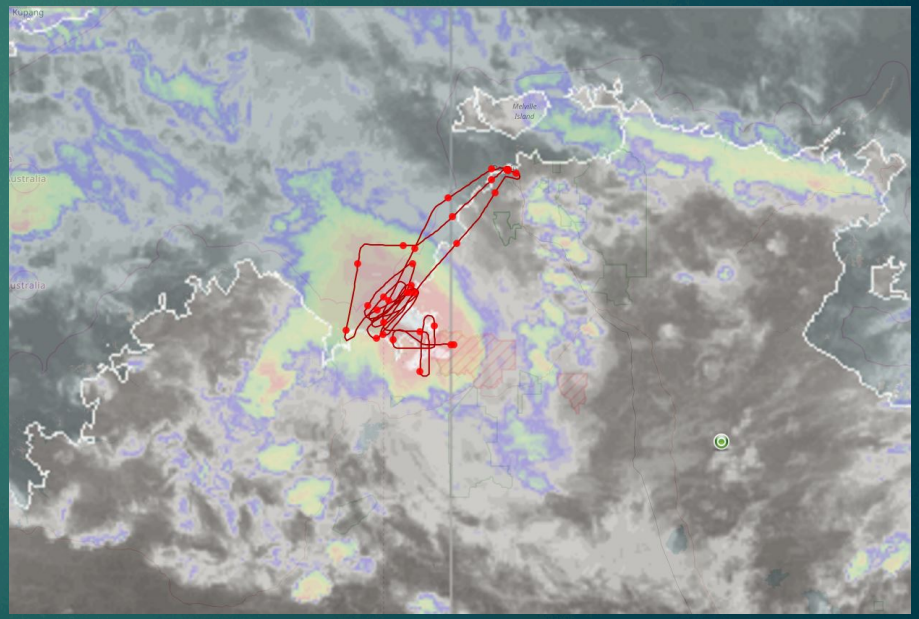


MMD-IWC Correlations

- Flight 12/13 very close to land.



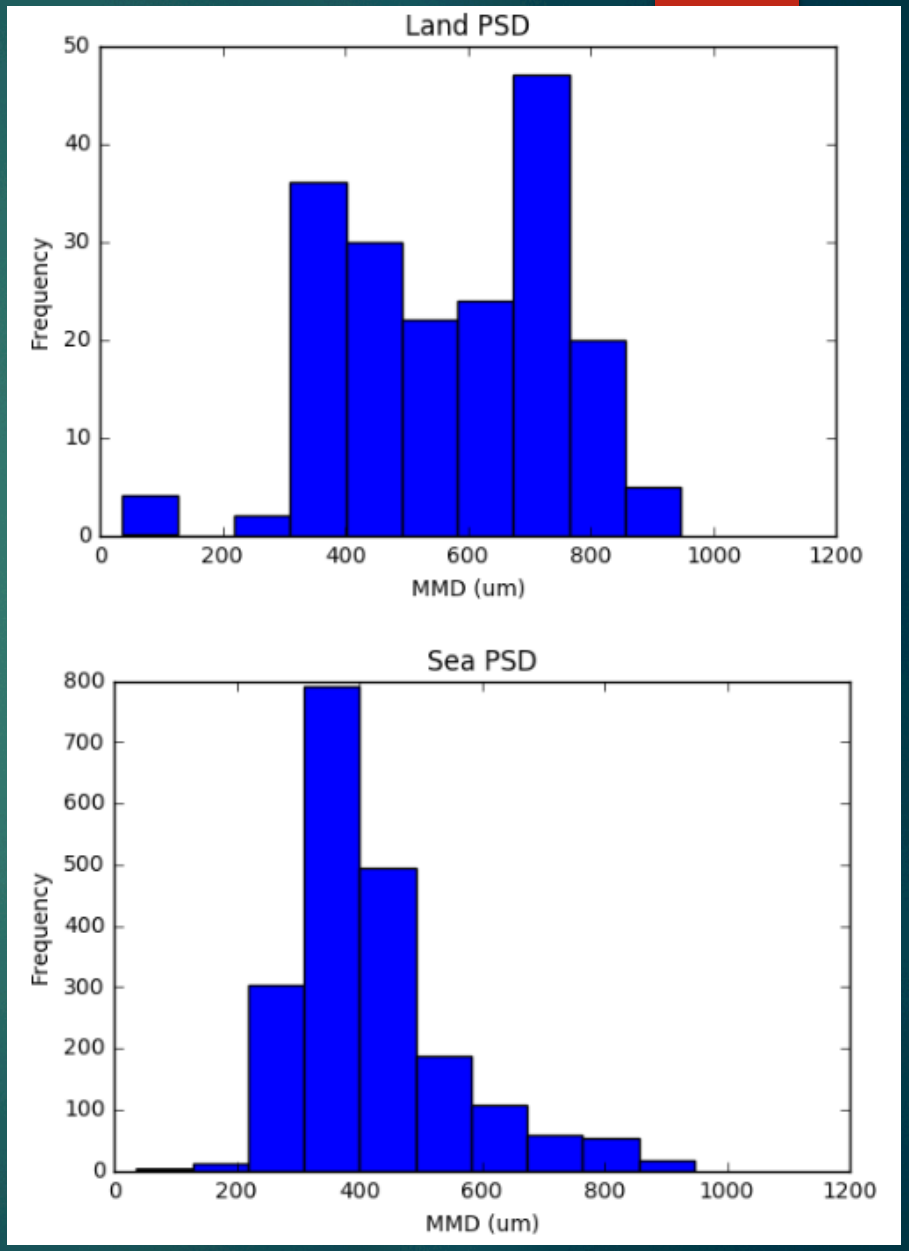
Flight 12

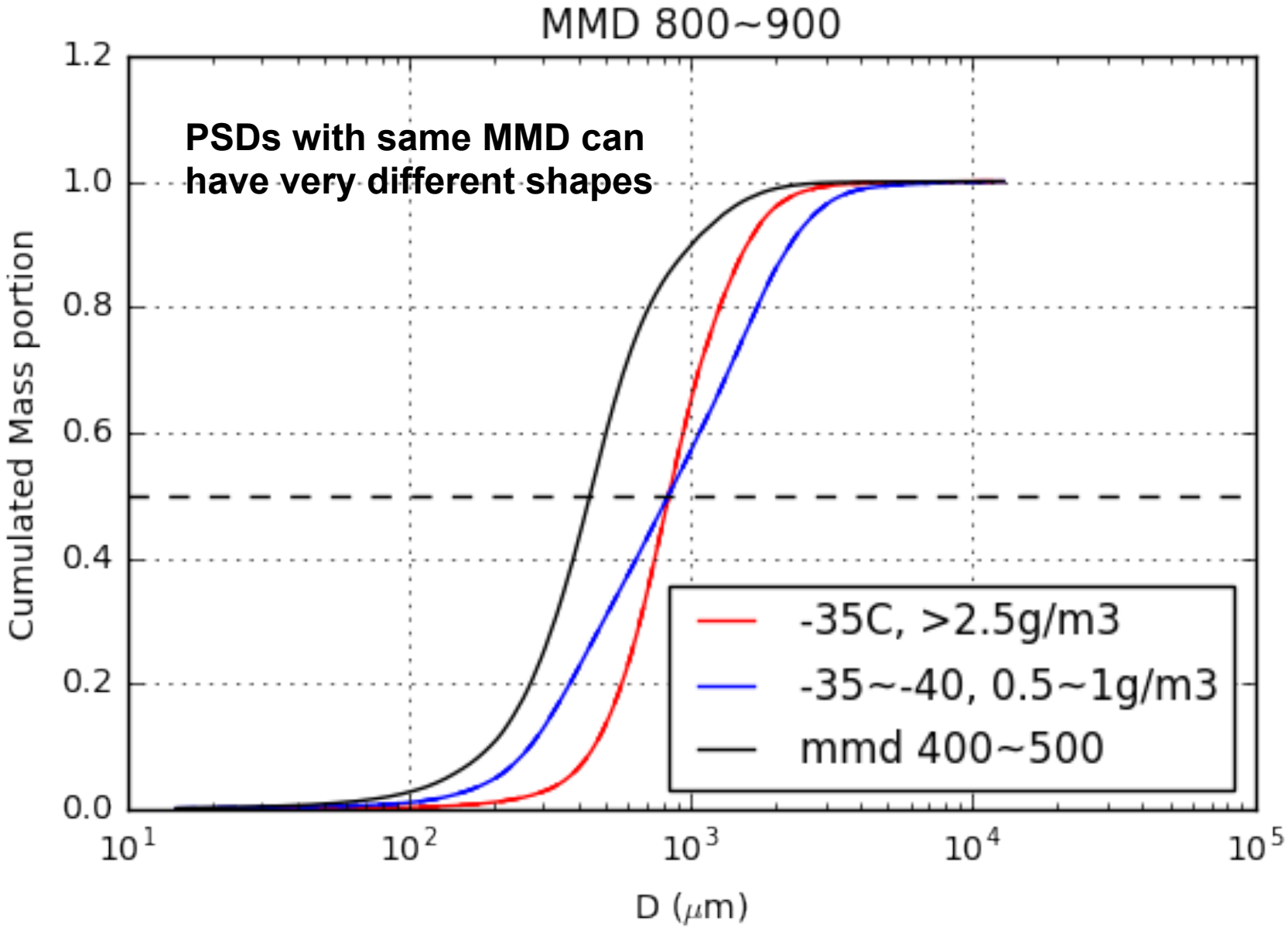


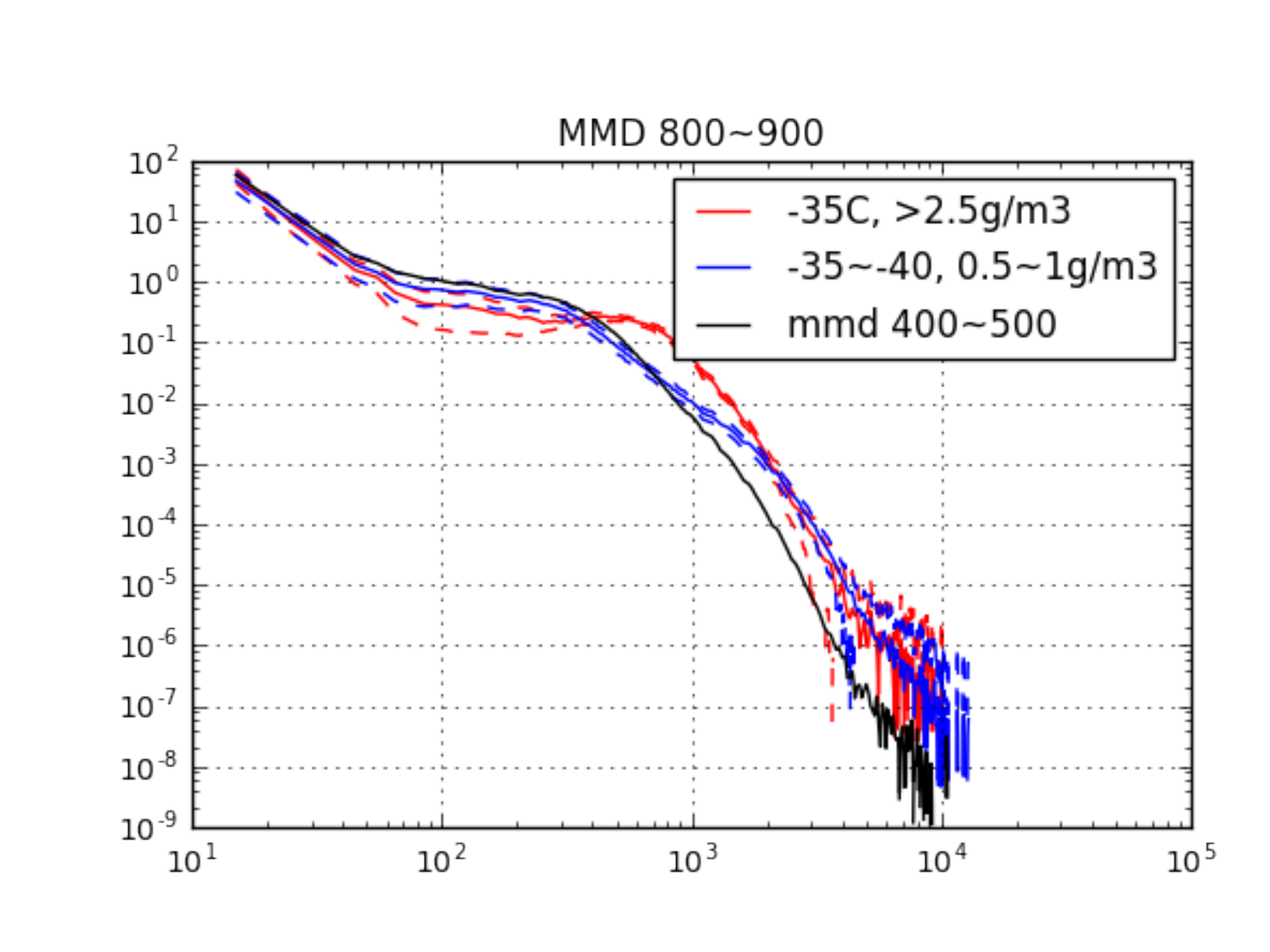
Flight 13

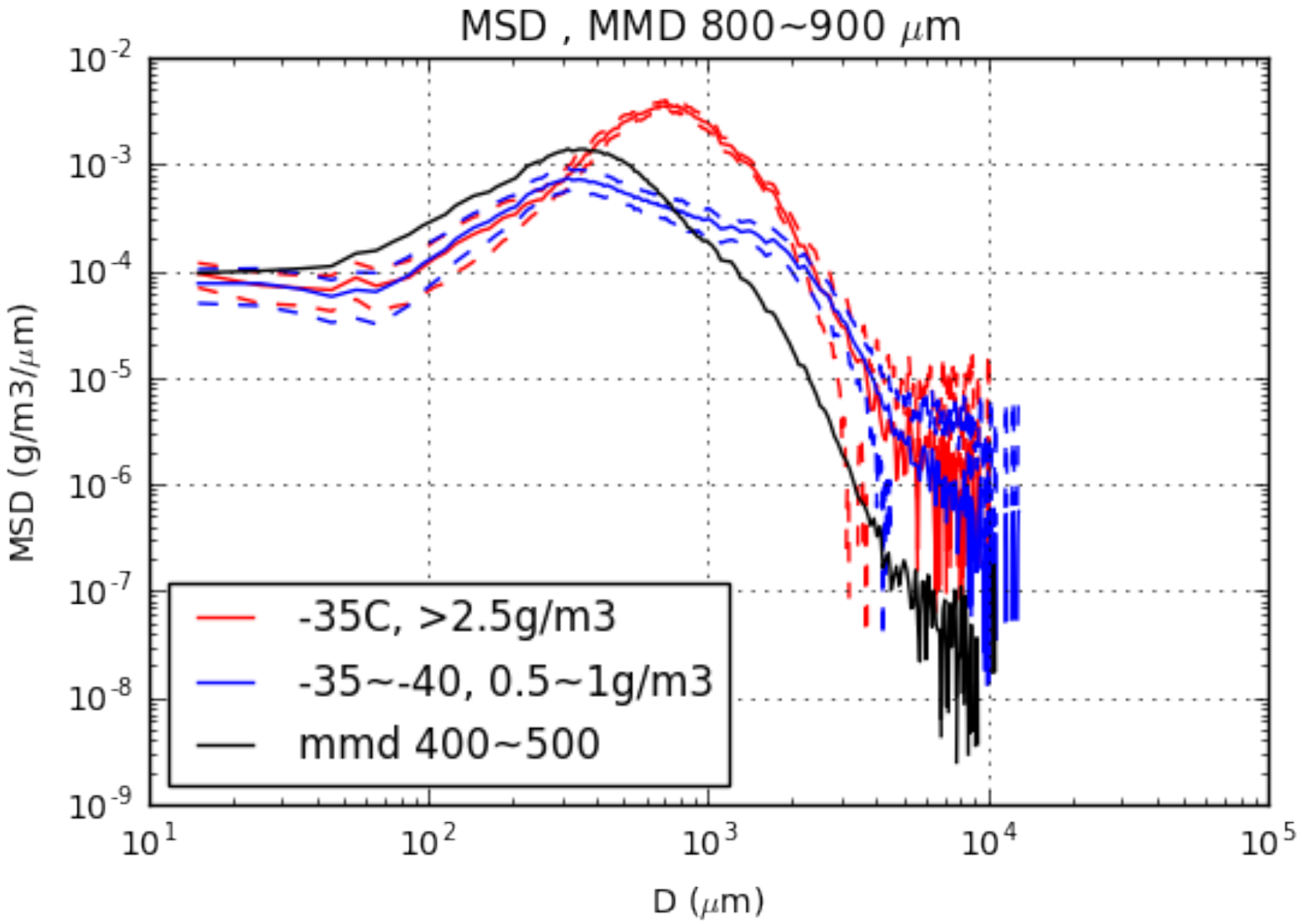
Land/sea MMD

- Larger range of MMD over land
- MMD mainly between 200-500μm over oceanic sampling.




MMD 800~900
PSDs with same MMD can have very different shapes
Cumulated Mass portion
D (μm)
-35C, >2.5g/m3
-35~-40, 0.5~1g/m3
mmd 400~500

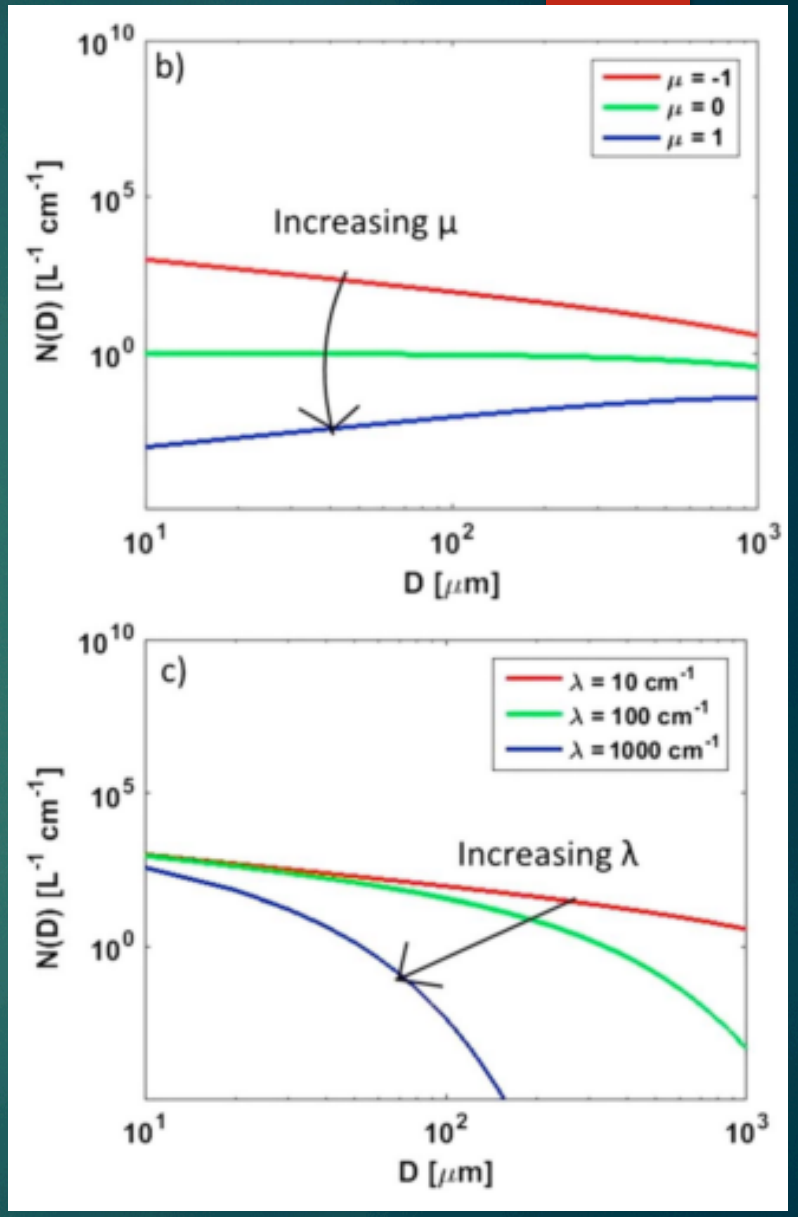

MMD 800~900
-35C, >2.5g/m3
-35~-40, 0.5~1g/m3
mmd 400~500
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}

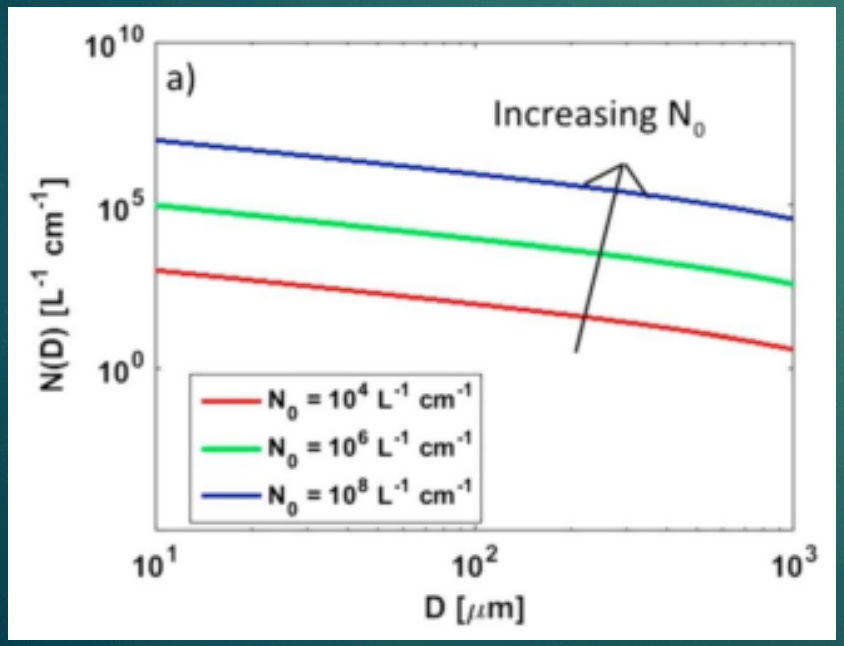

MSD , MMD 800~900 μm
MSD (g/m3/μm)
D (μm)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
-35C, >2.5g/m3
-35~-40, 0.5~1g/m3
mmd 400~500

Gamma Function Fits

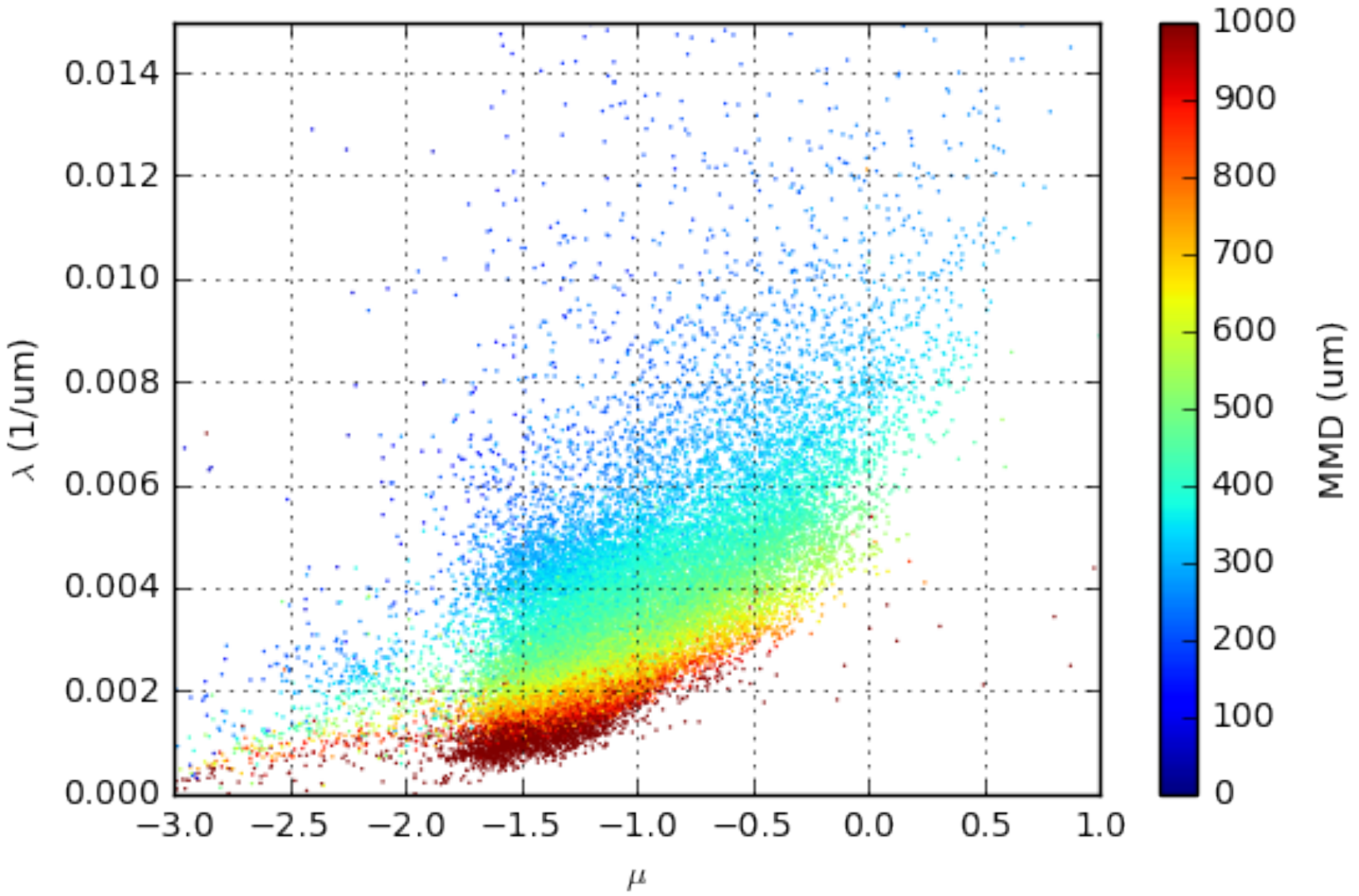
- $N(D) = N_0 D^{\mu} e^{-\lambda D}$
- N_0, μ, and λ calculated from Incomplete Gamma Fit (IGF) that minimizes χ^2 difference between fit and observed moments
- Any (N_0,μ,λ) within $\Delta\chi^2$ of minimum χ^2 regarded as equally realizable solution
- $\Delta\chi^2$ determined from statistical uncertainty on measured moments on which fit based and variability of SDs
  - Variability is dominant source of error for HAIC/HIWC data, so only show best estimates for each fit today

Gamma Distribution

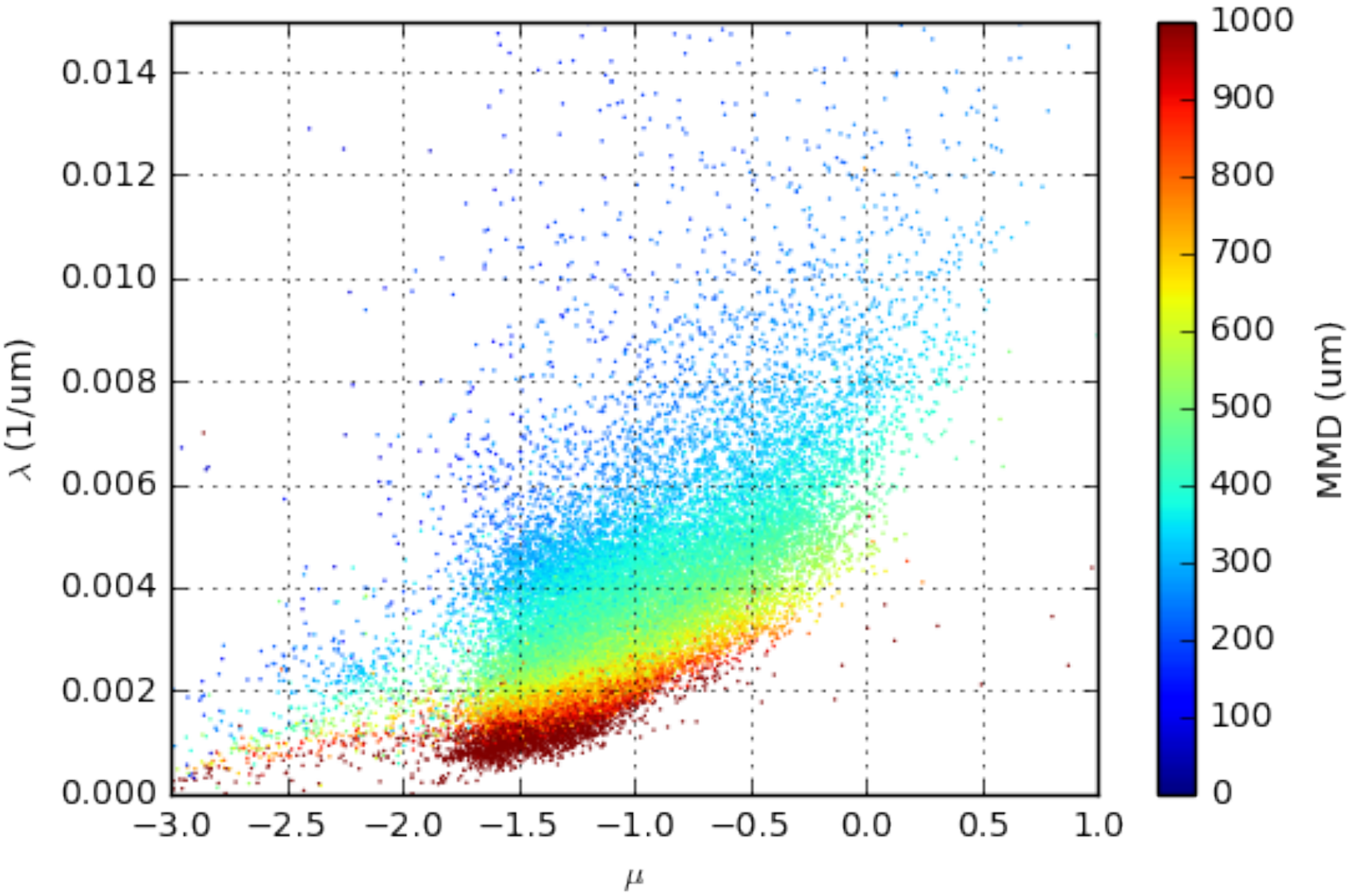




[Jackson et al 2015]


0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
λ (1/um)
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
μ
1000
900
800
700
600
500
400
300
200
100
0
MMD (um)

There are definite differences in shape of PSDs in λ/μ phase space depending on MMD



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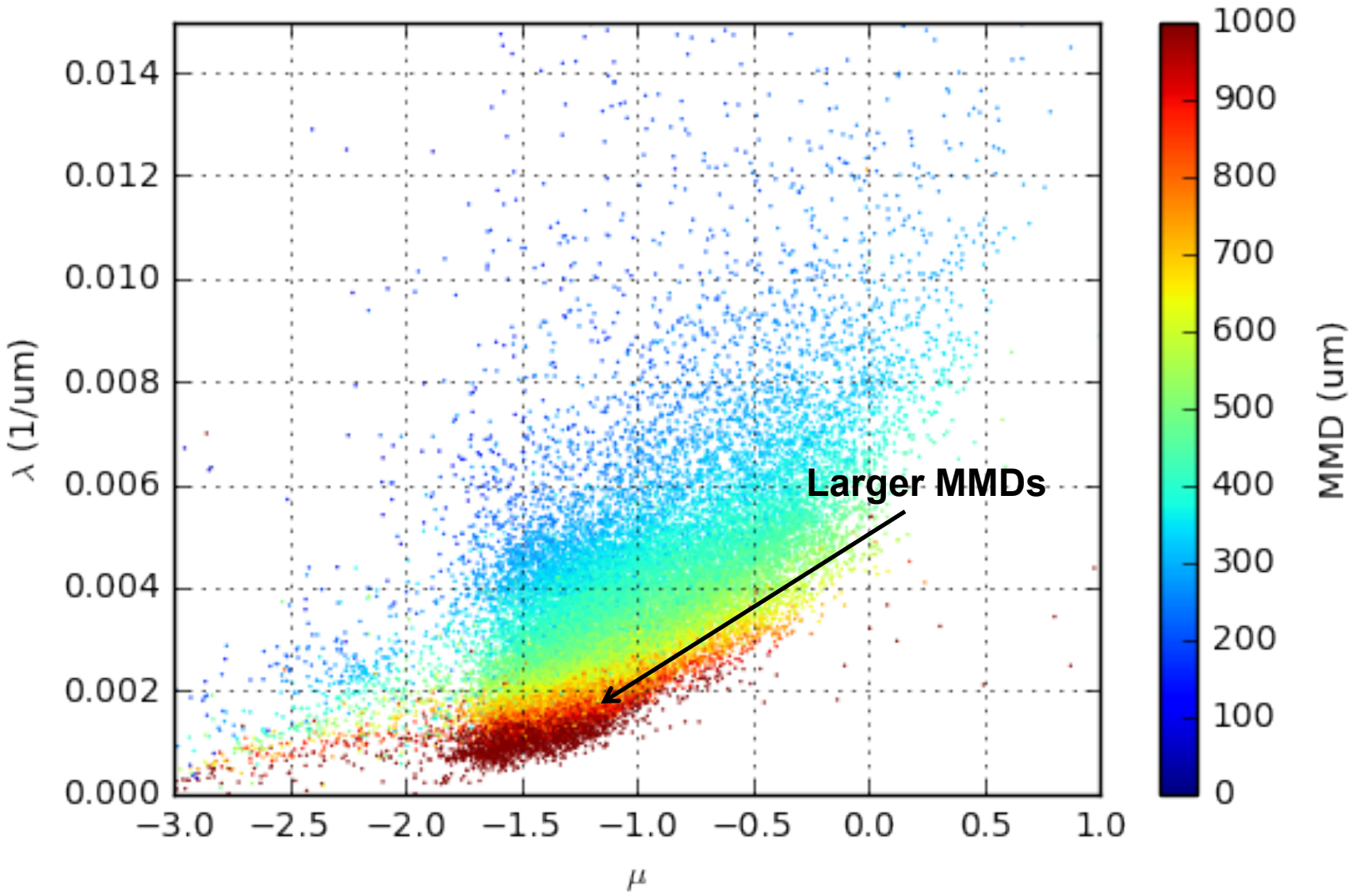

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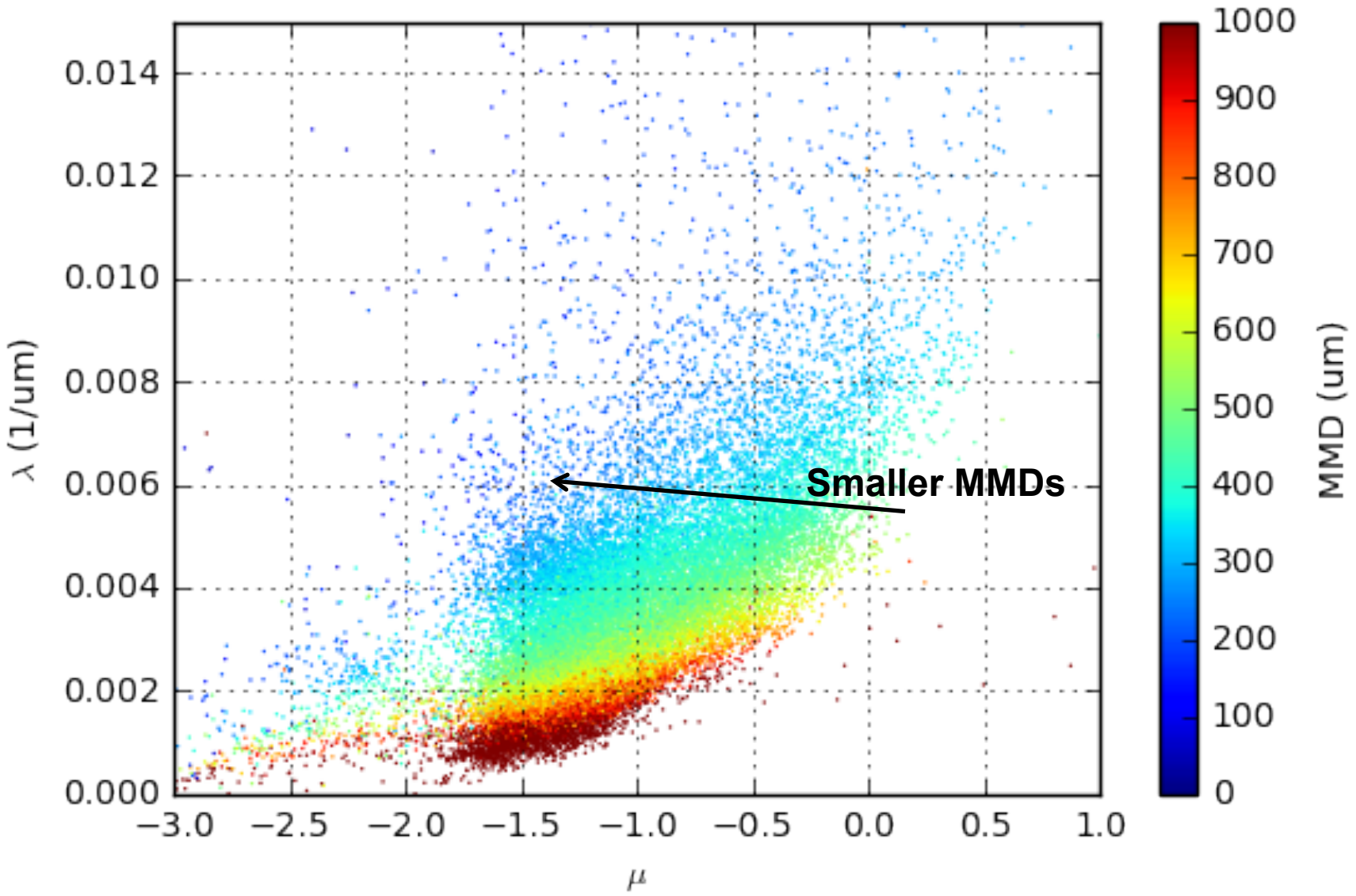
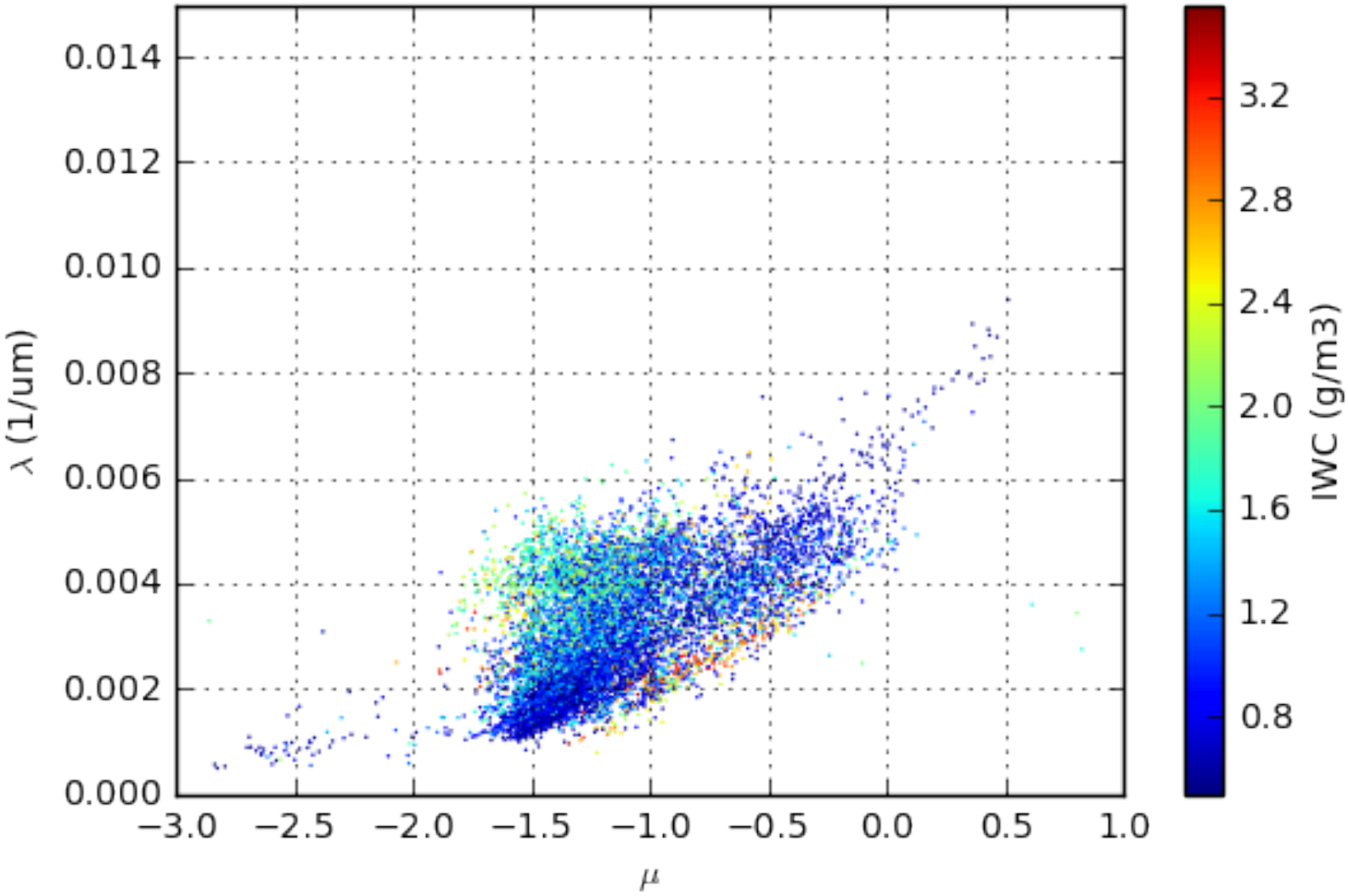
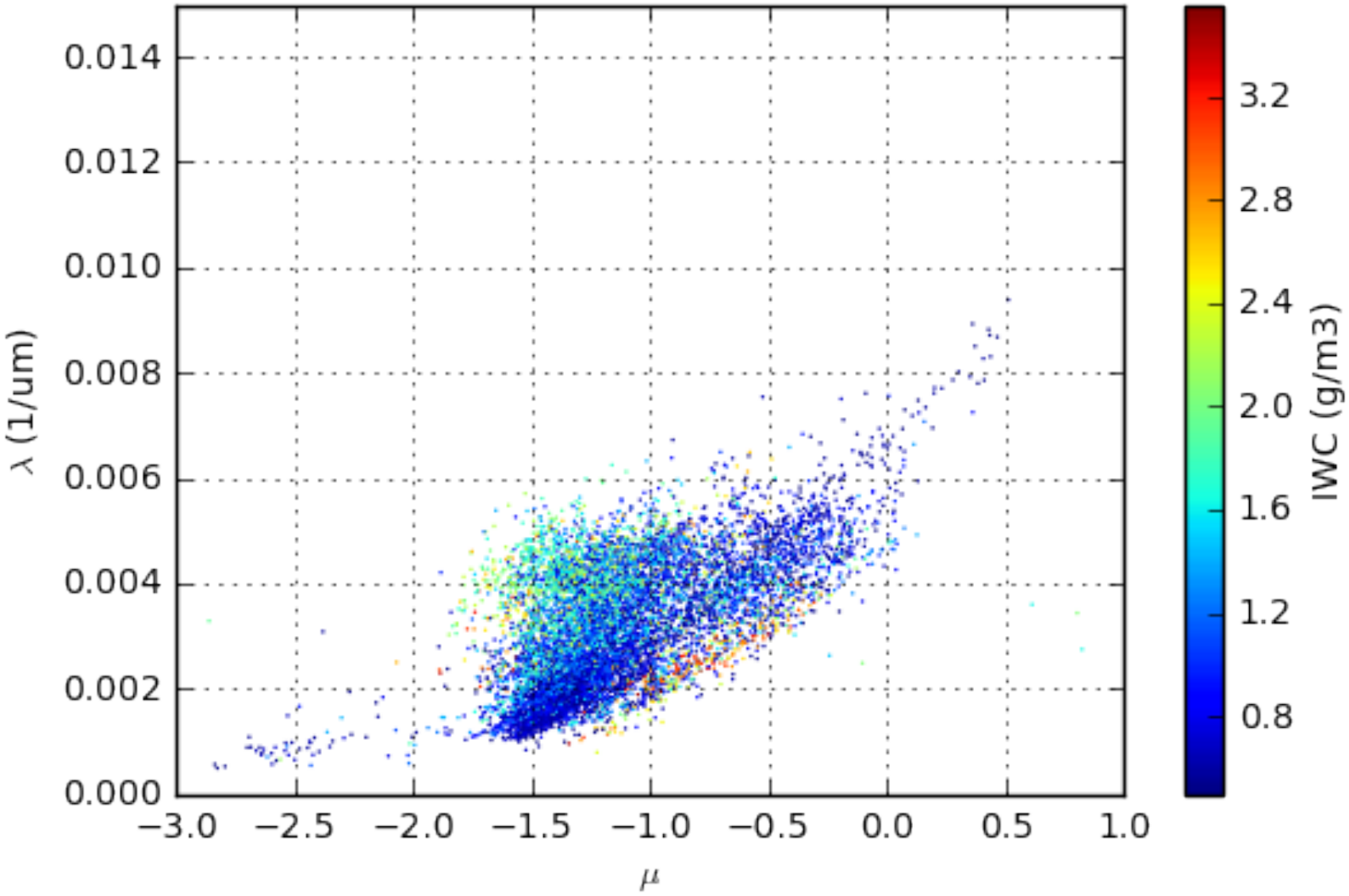


Variations in λ/μ phase space depending on IWC is not as strong



Variations in λ/μ phase space depending on IWC is not as strong; higher IWCs seem to have 2 distinct populations



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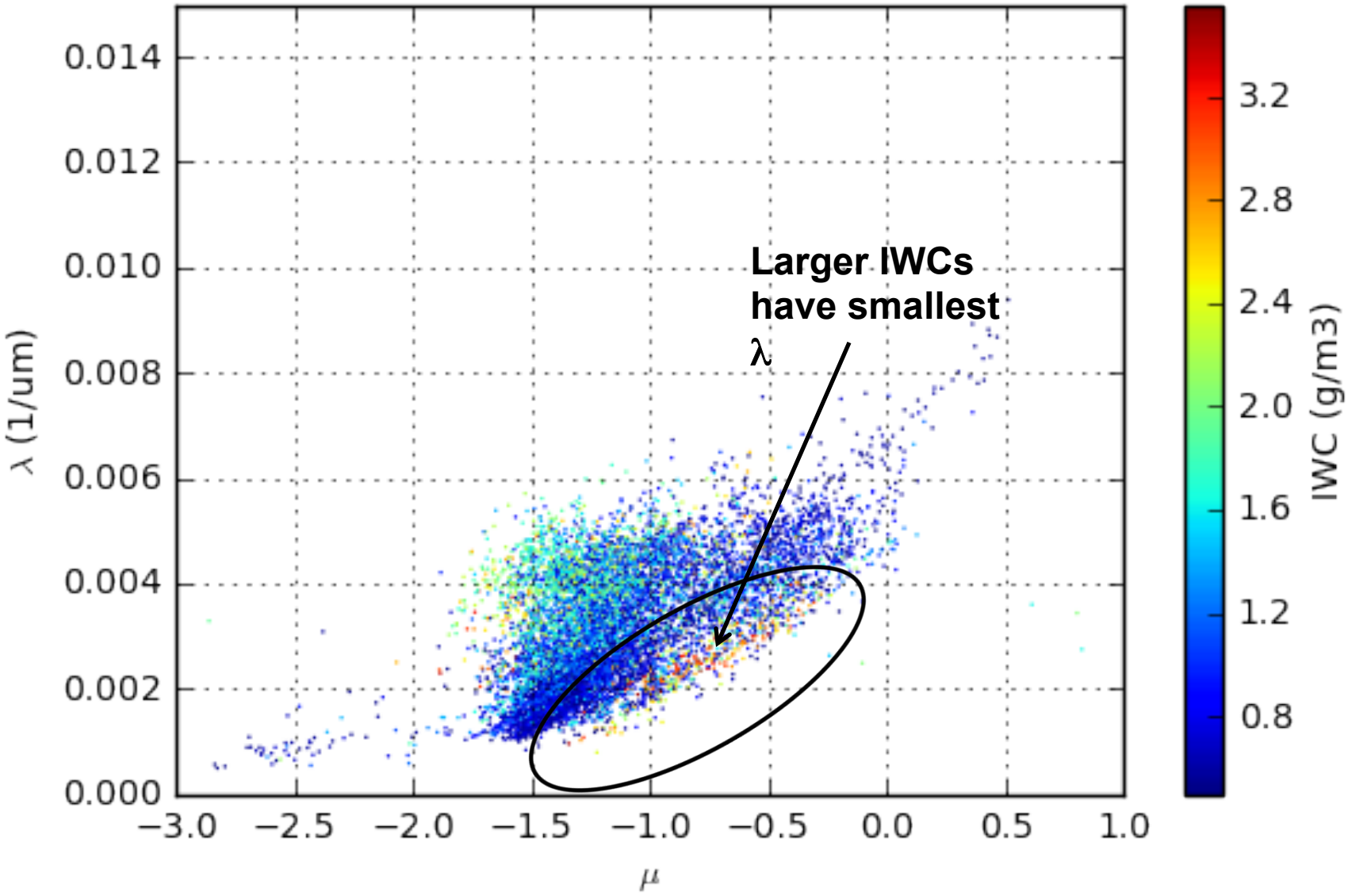

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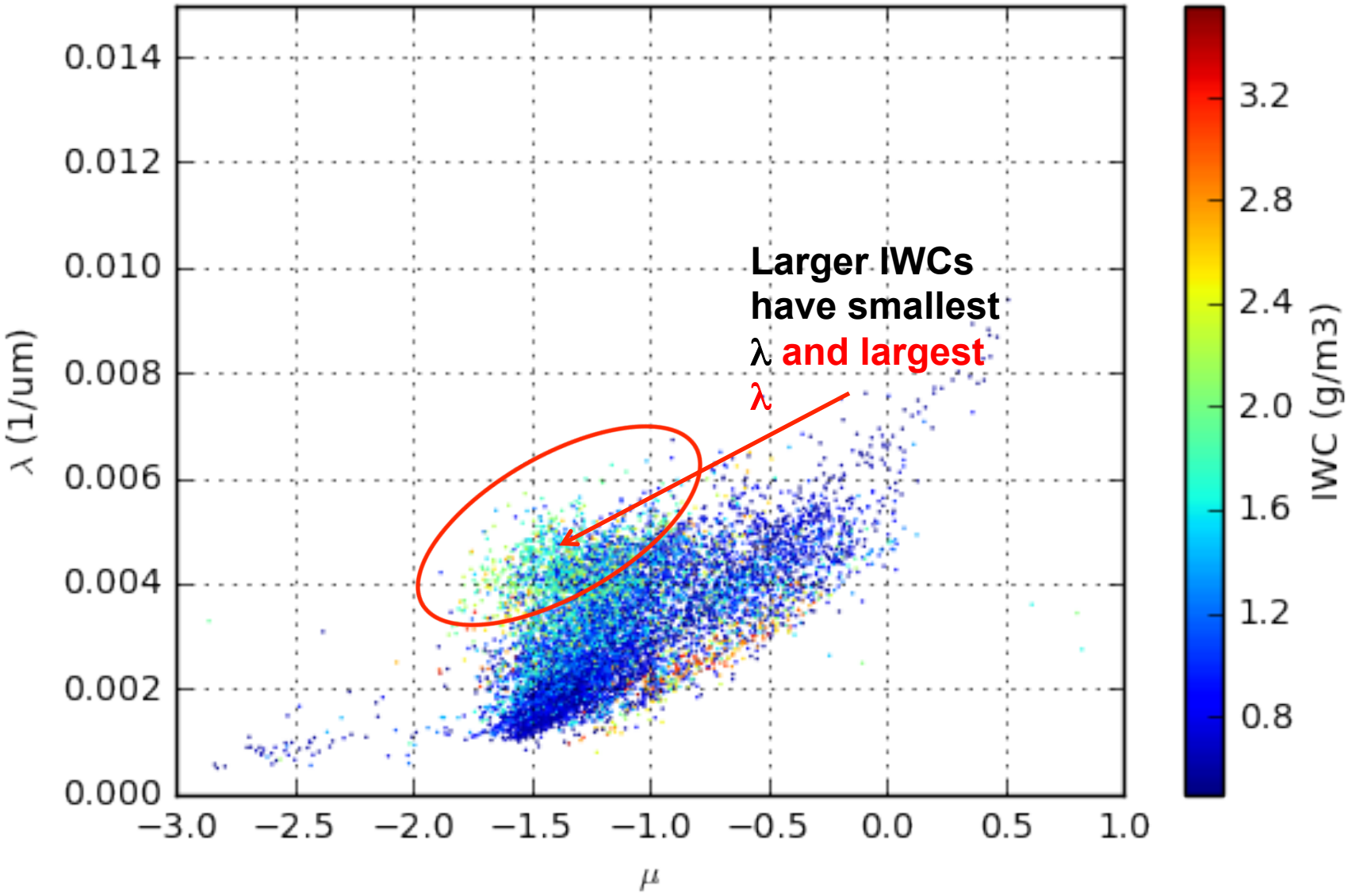
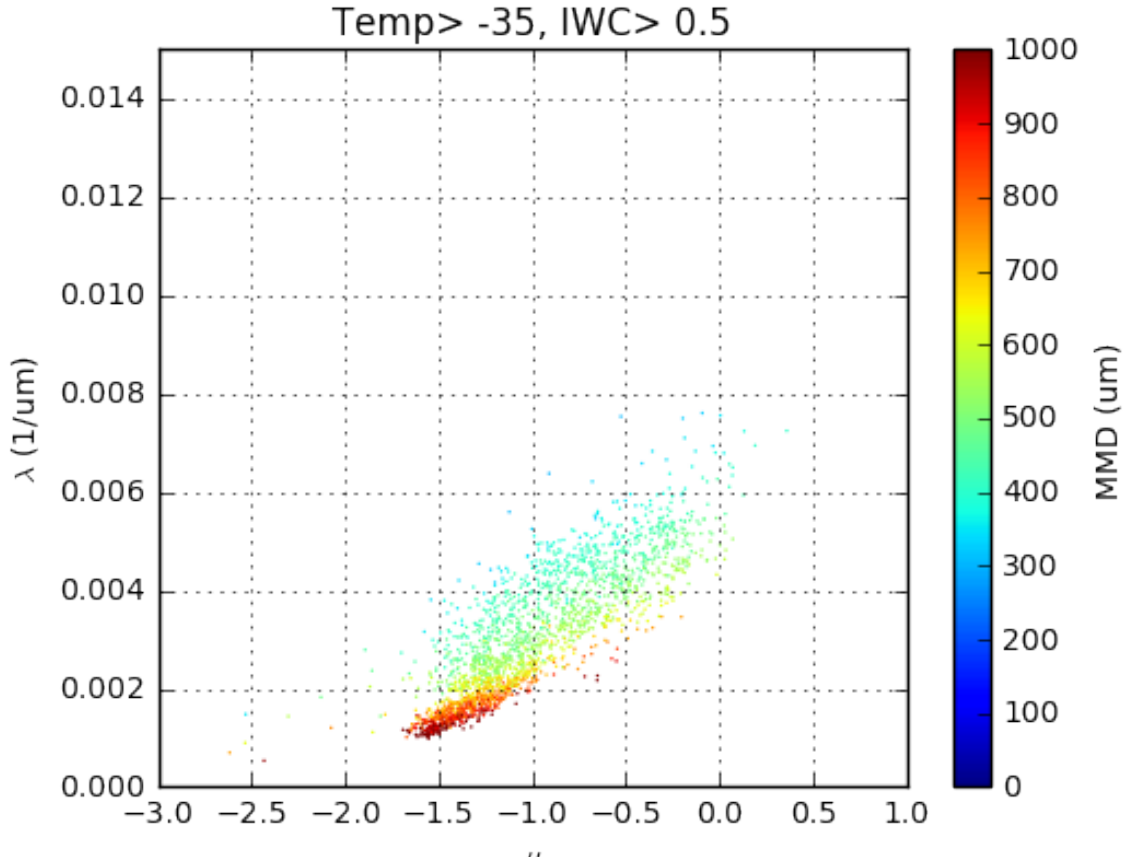
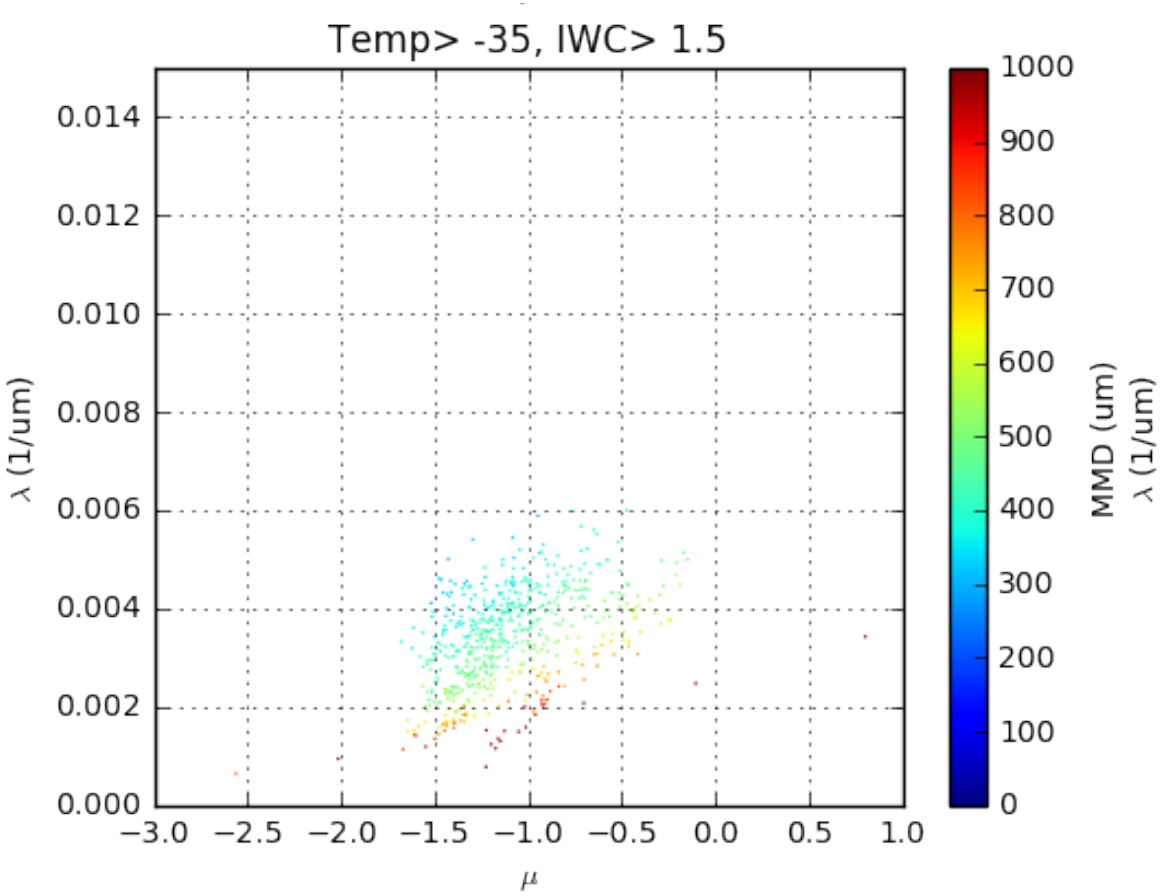



Temp> -35, IWC> 0.5
λ (1/um)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1000
900
800
700
600
500
400
300
200
100
0
MMD (um)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0.014
0.012
0.010
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0.006
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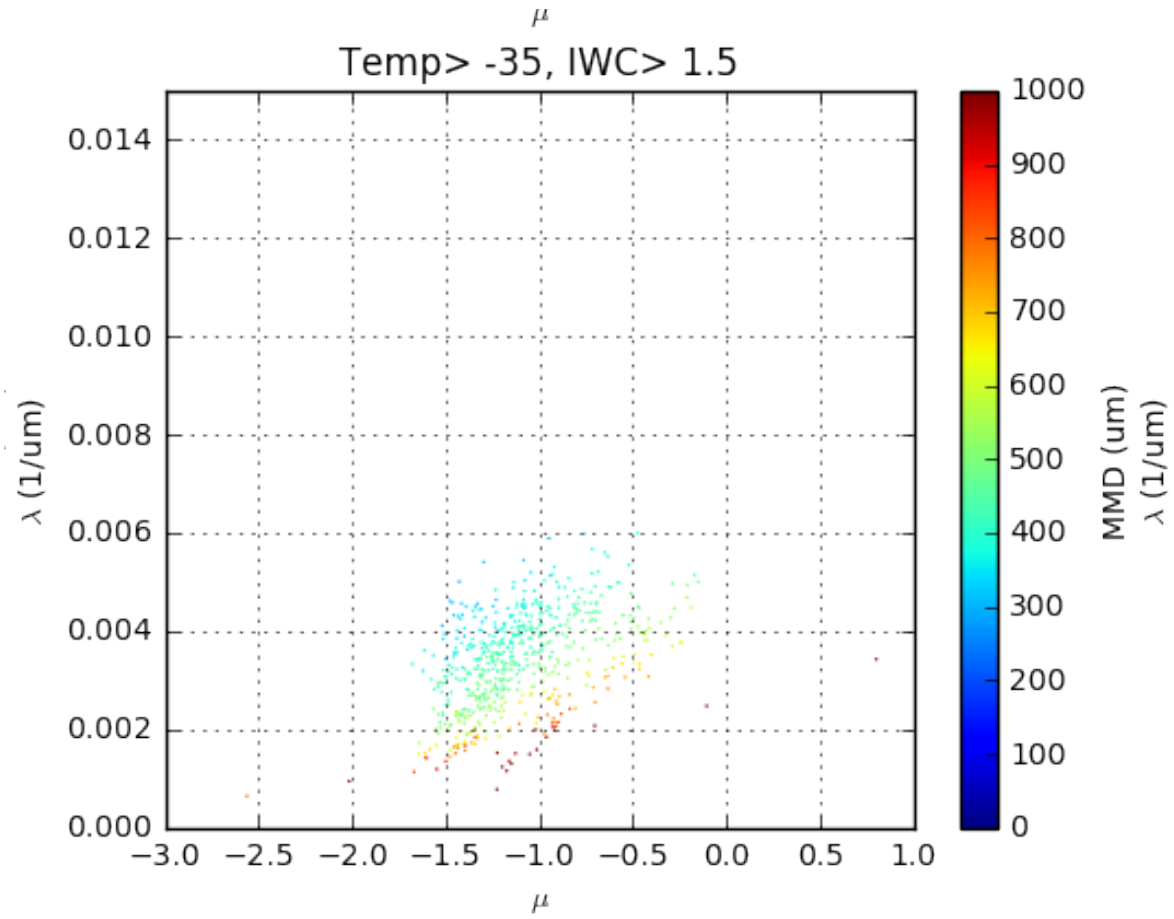
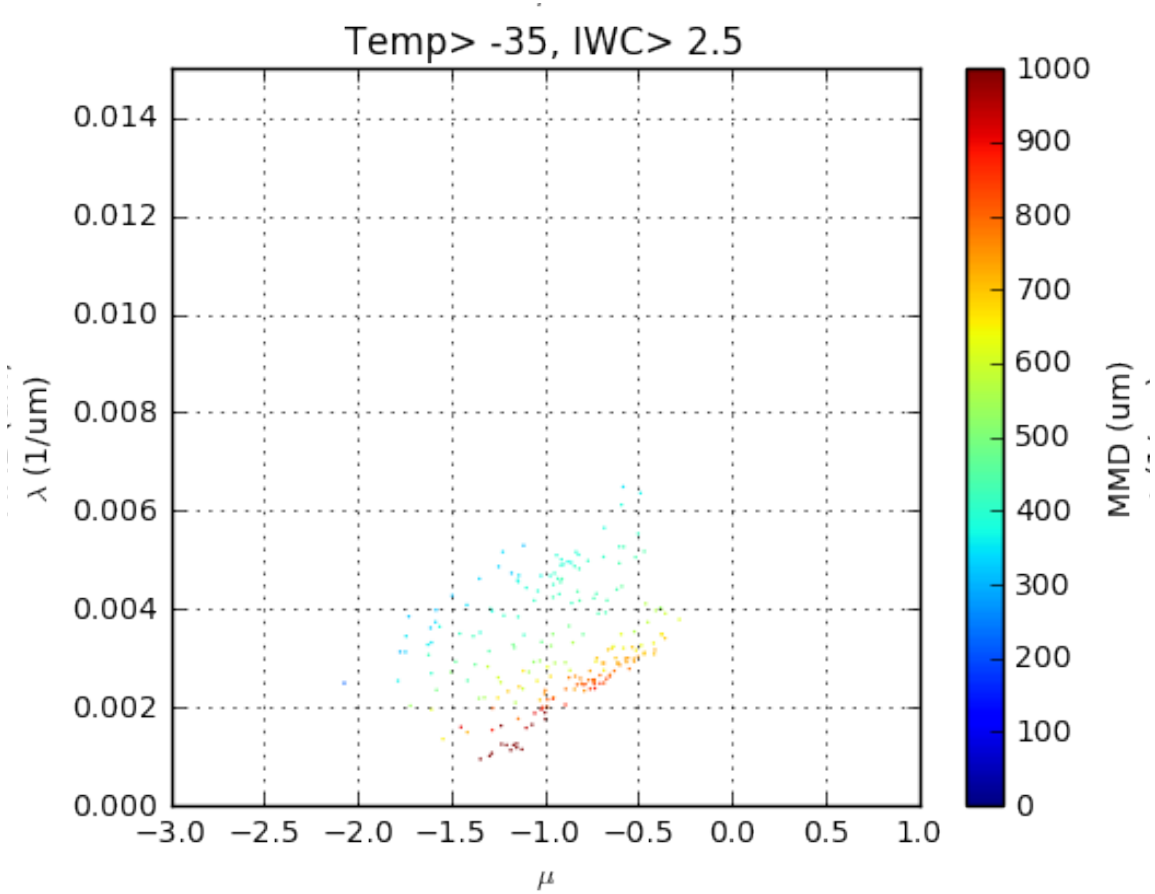
0.000
λ (1/um)
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
μ
1000
900
800
700
600
500
400
300
200
100
0
MMD (um)
λ (1/um)



As IWC increases, capture points only with higher and lower values of λ



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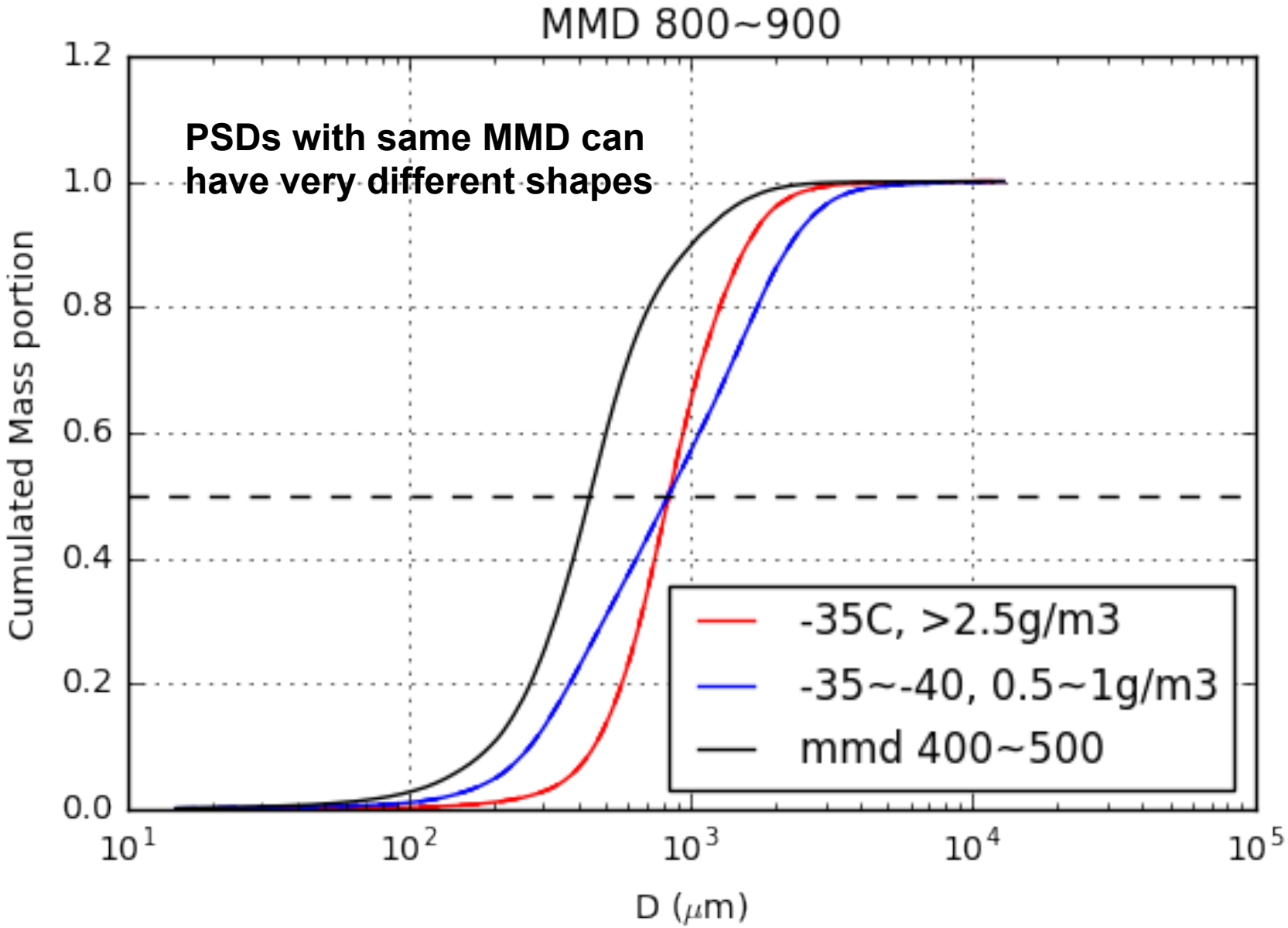
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-35~-40, 0.5~1g/m3
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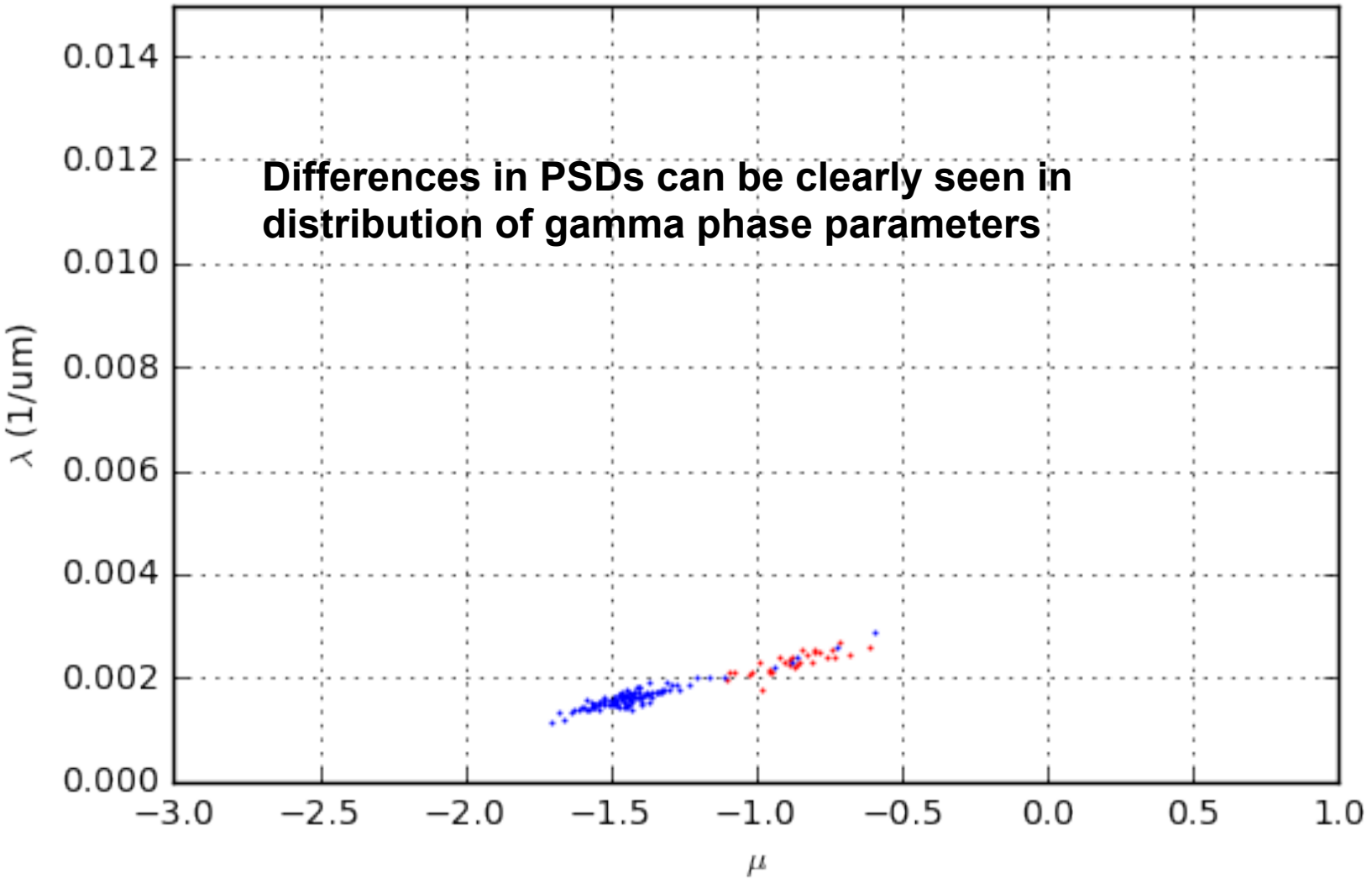
Differences in PSDs can be clearly seen in distribution of gamma phase parameters
0.014
0.012
0.010
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0.006
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0.002
0.000
λ (1/um)
−3.0
−2.5
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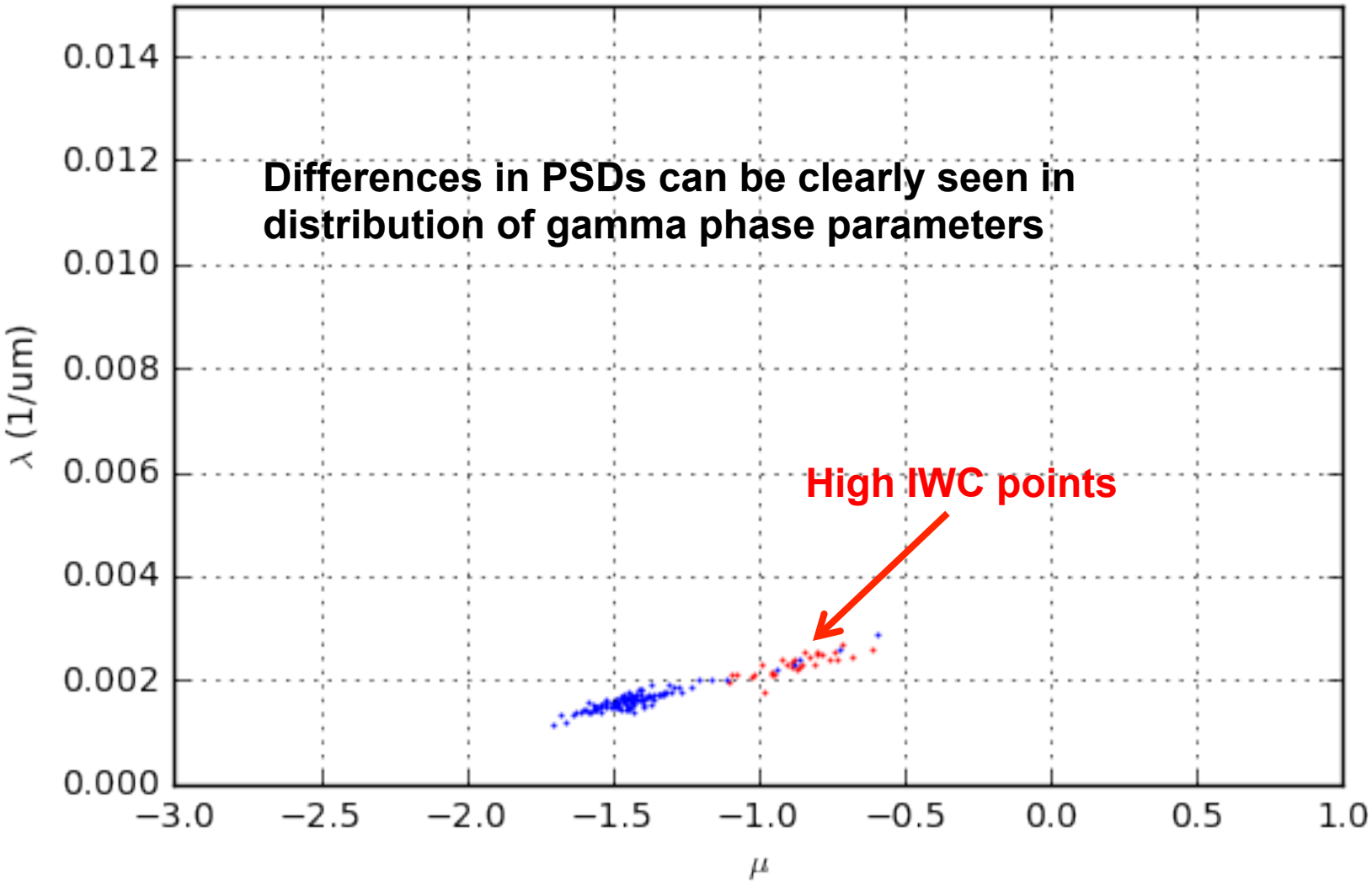
−1.0
−0.5
0.0
0.5
1.0
μ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0.002
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λ (1/um)
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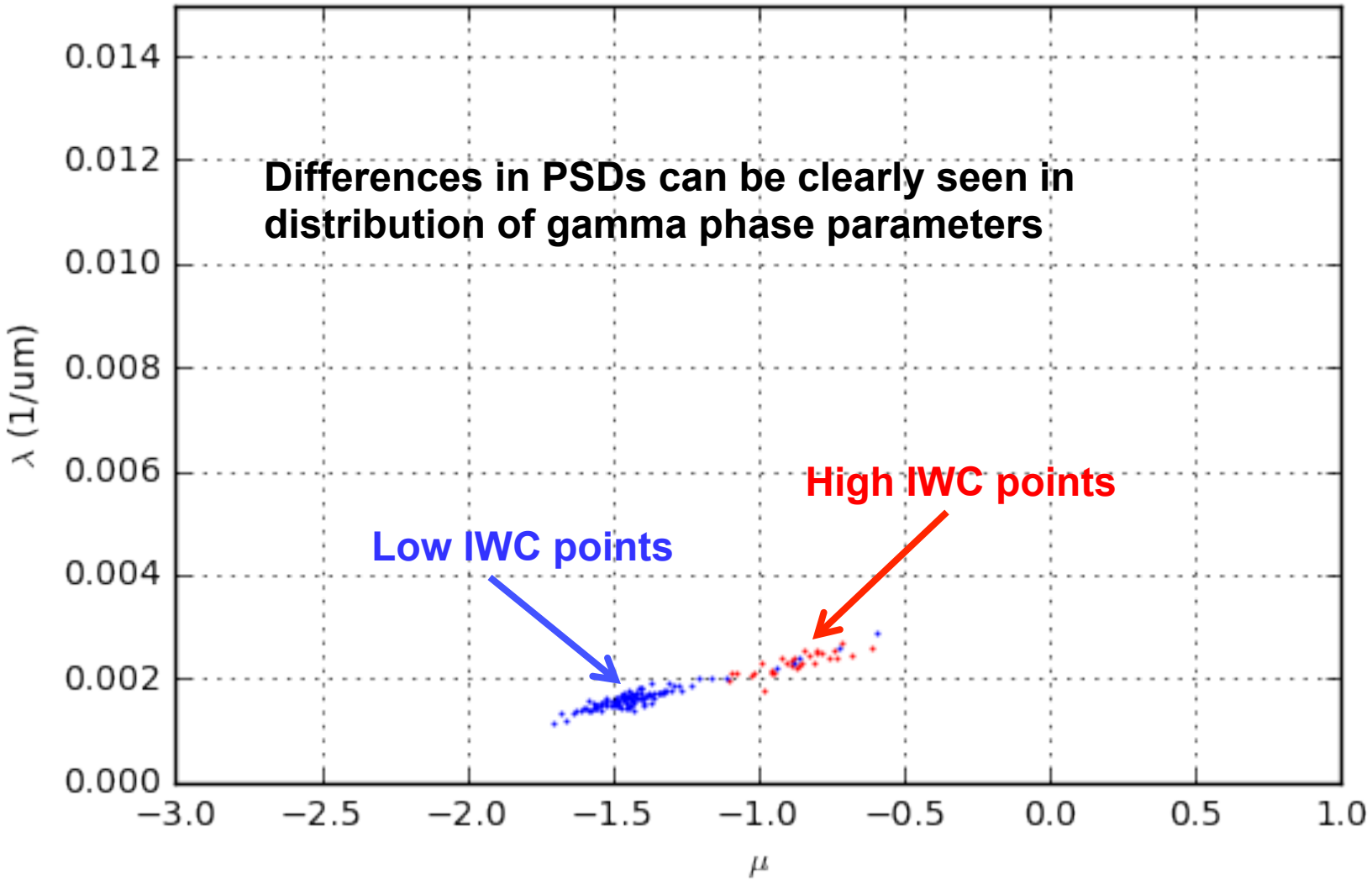
−1.5
−1.0
−0.5
0.0
0.5
1.0
μ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High IWC points
Low IWC points
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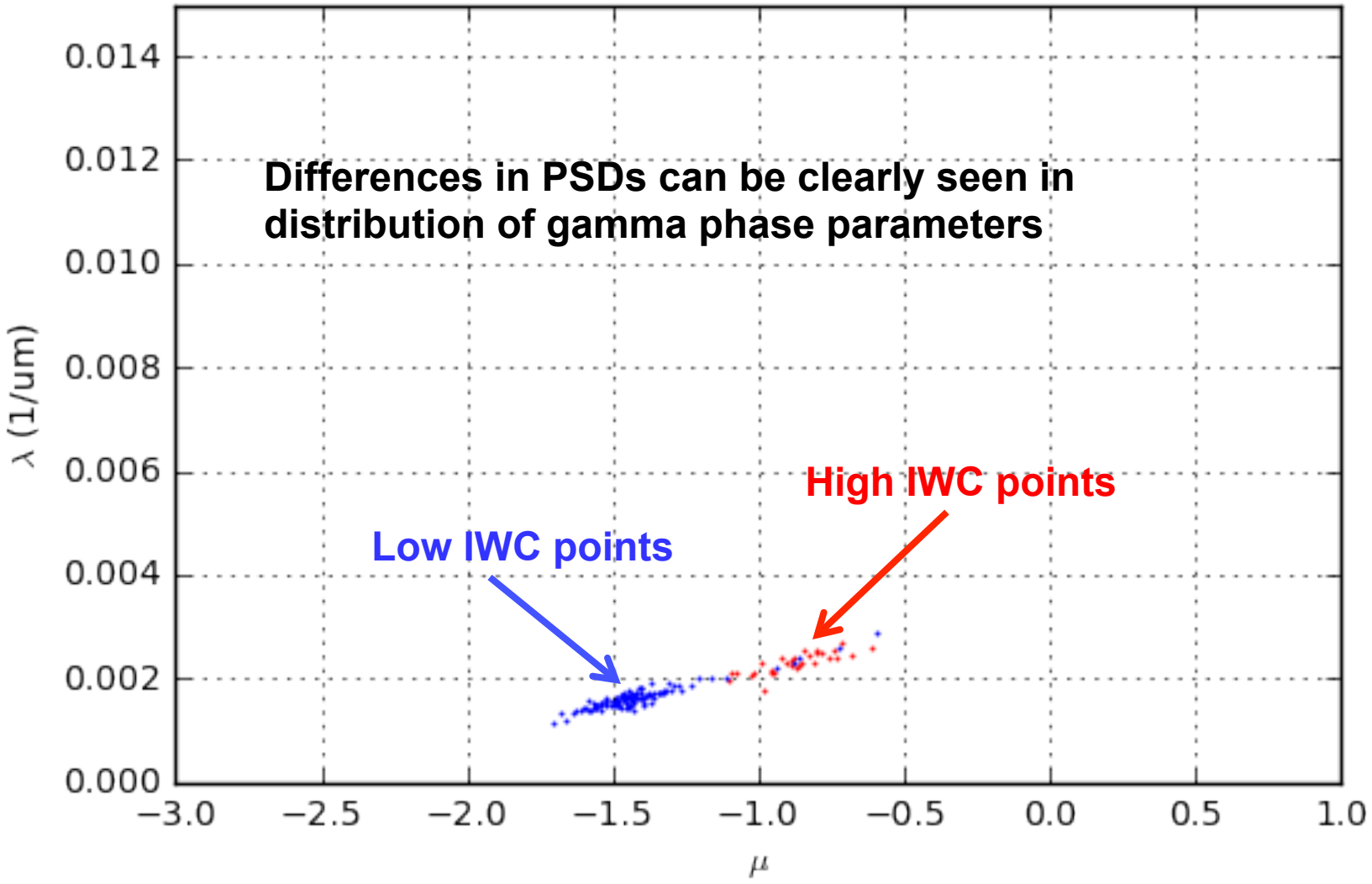
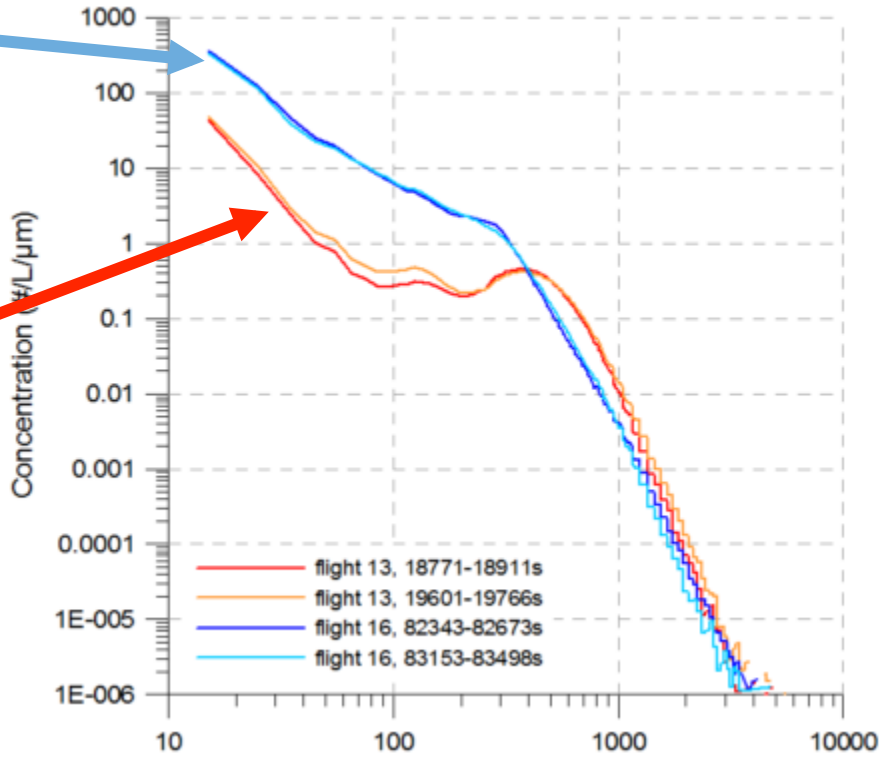
−1.5
−1.0
−0.5
0.0
0.5
1.0
μ



What controls PSDs and MMDs?

Particle Size Distribution (PSD)

- One mode PSD that resembles a gamma distribution.
- Double mode PSD that is harder to fit to a gamma distribution.



Particle Size Distribution (PSD)

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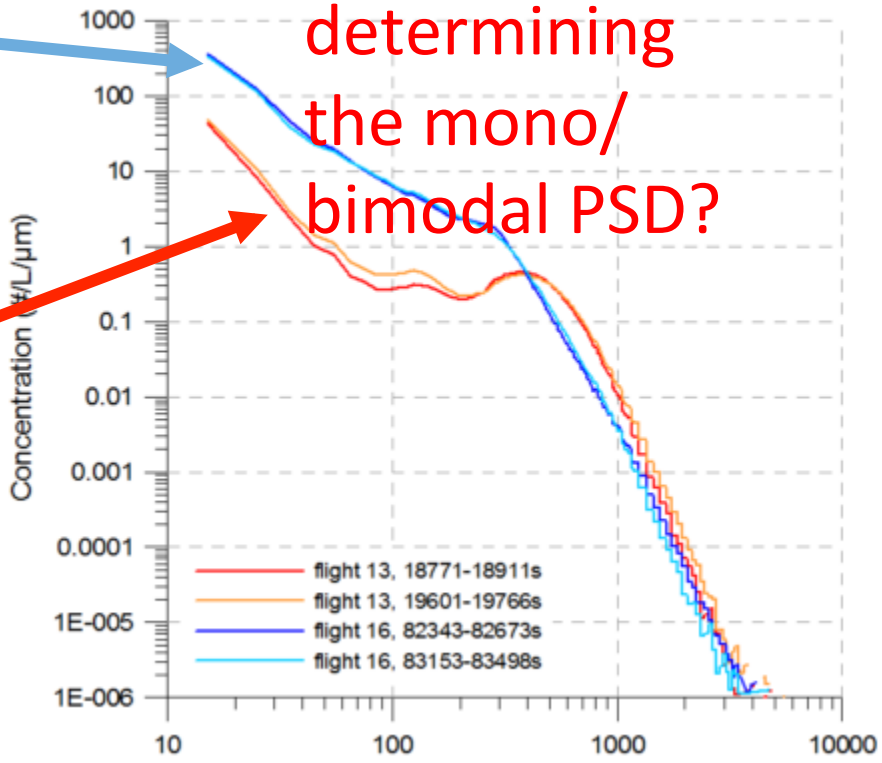
- Double mode PSD has larger Median Mass Diameter.

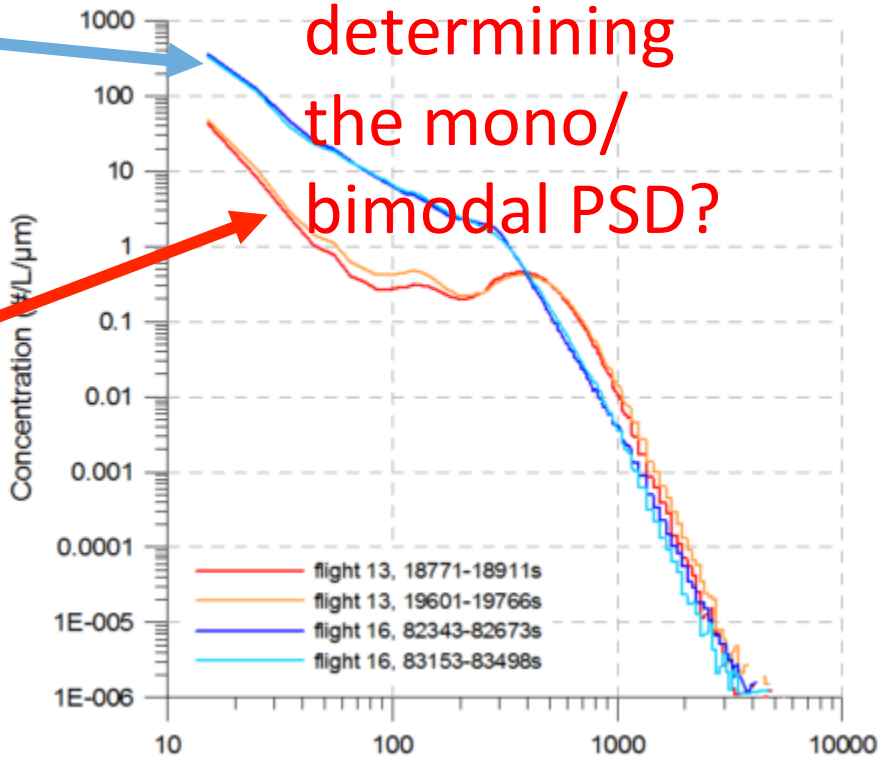
What is determining the mono/ bimodal PSD?



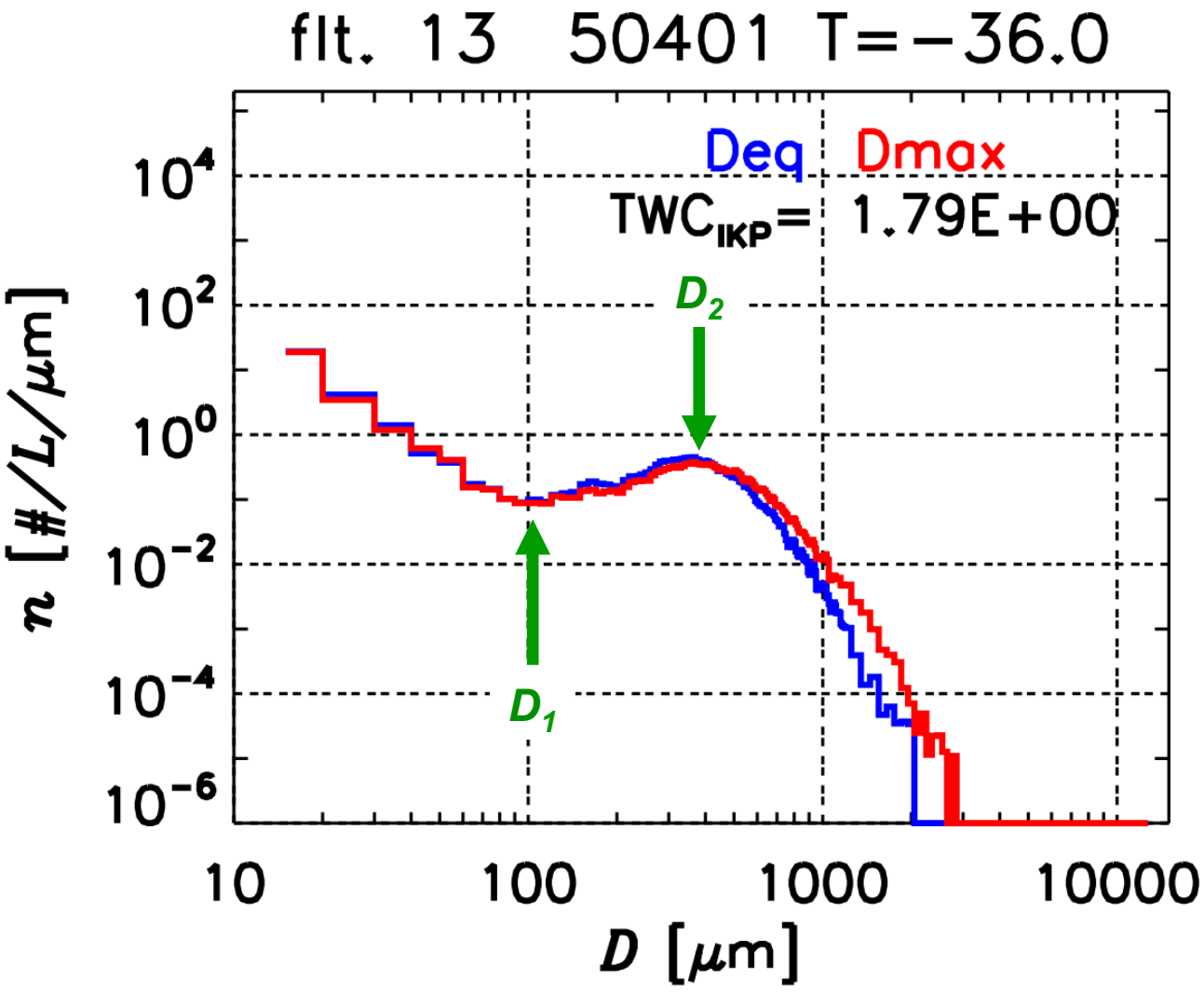
Particle Size Distribution (PSD)

- One mode PSD that resemble a gamma distribution.
- Double mode PSD that is harder to fit to a gamma distribution.
- Double mode PSD has larger Median Mass Diameter.
- Do our fits work for multi-mode PSDs?

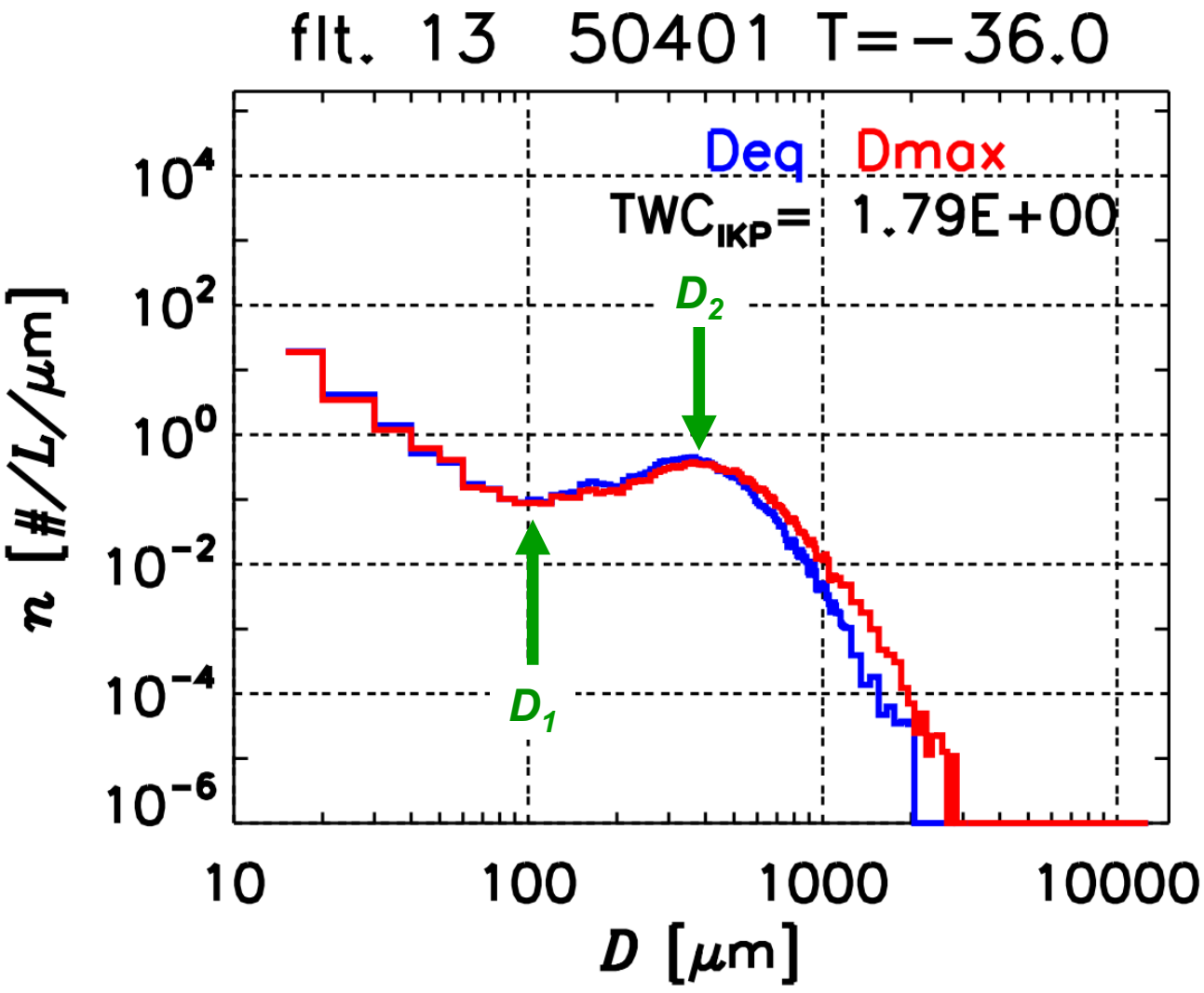
What is determining the mono/ bimodal PSD?



Exploring Nature of Multi-Modal Distributions

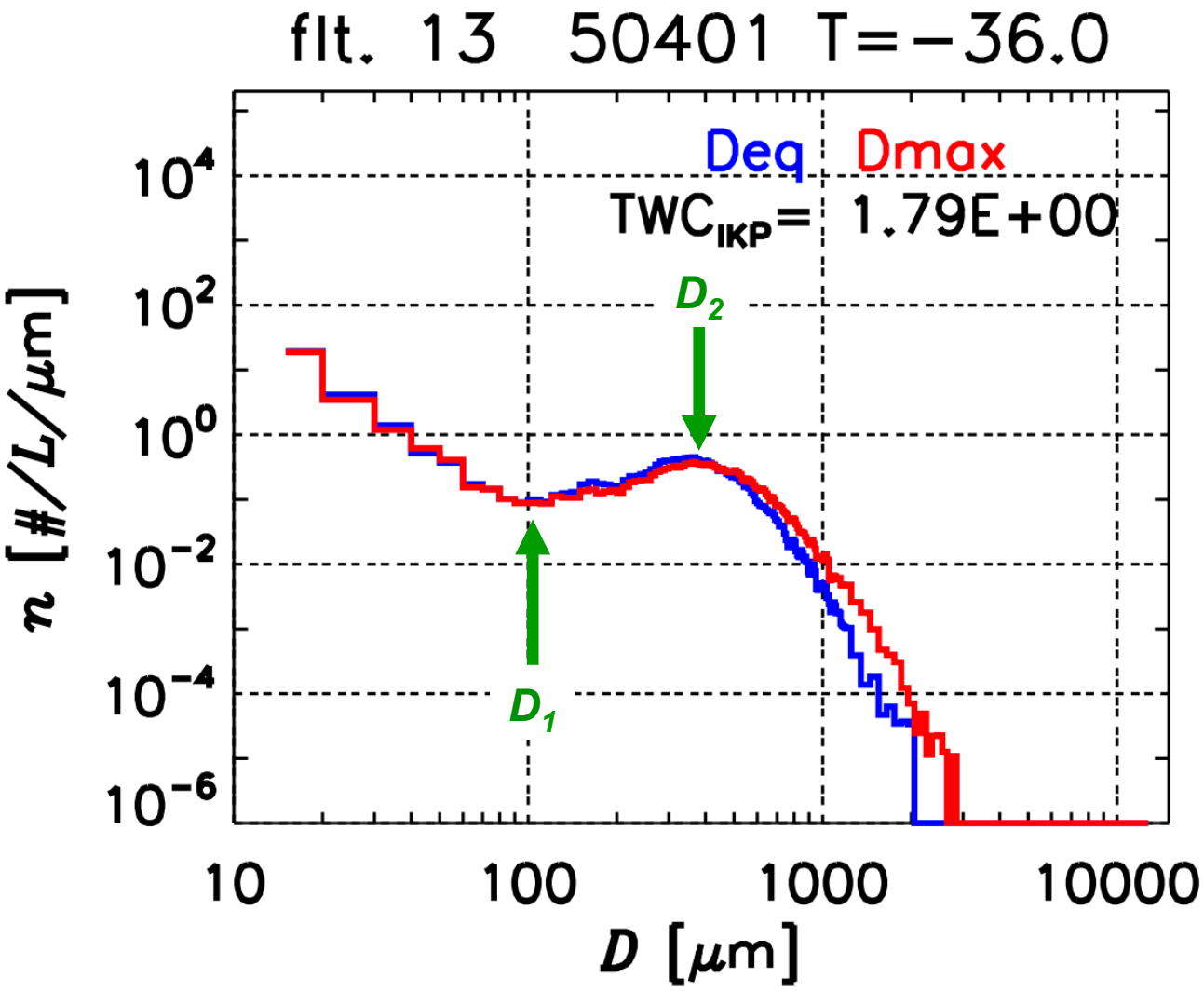


Exploring Nature of Multi-Modal Distributions



Automated technique for identifying D_1 and D_2

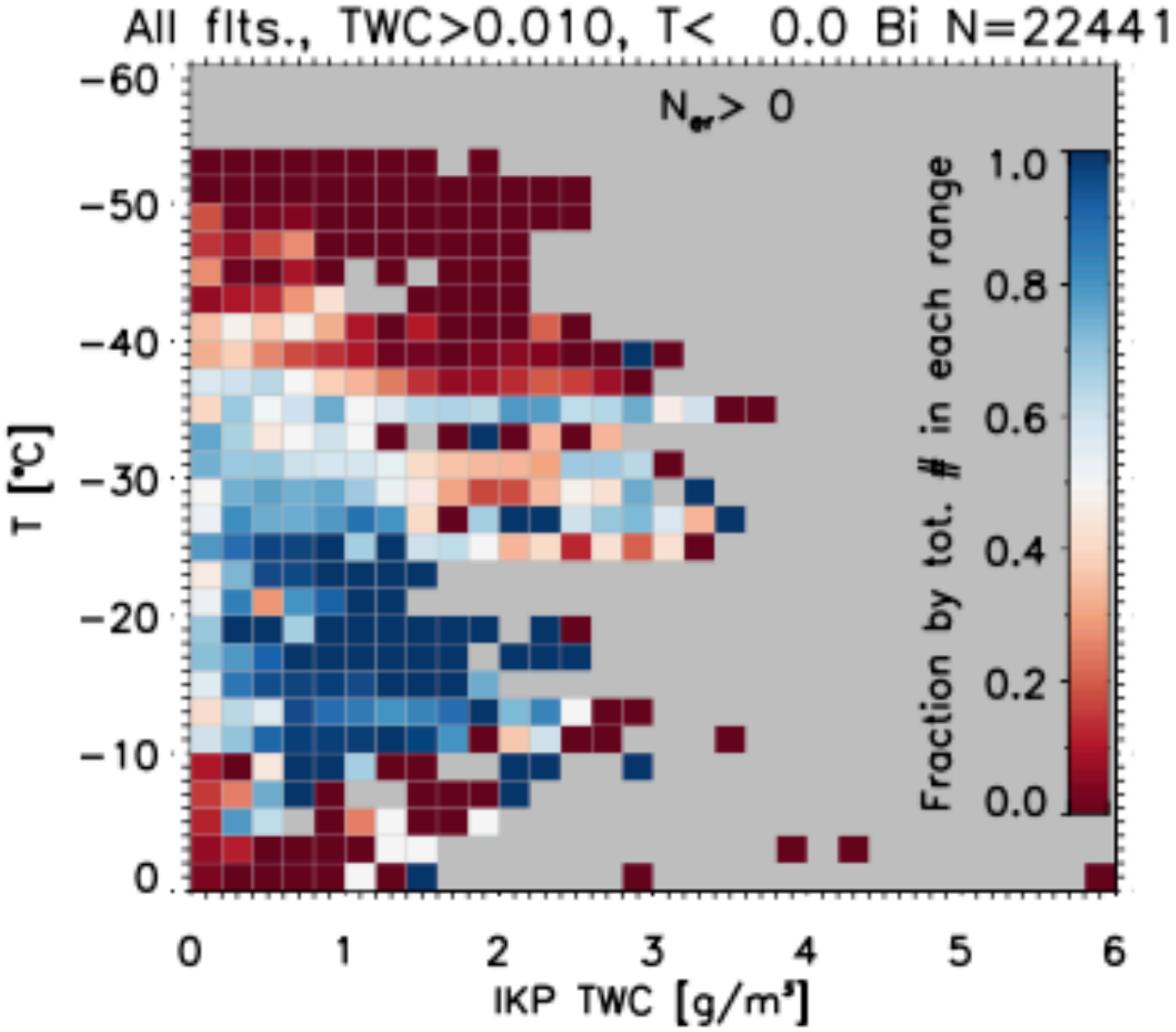
Exploring Nature of Multi-Modal Distributions



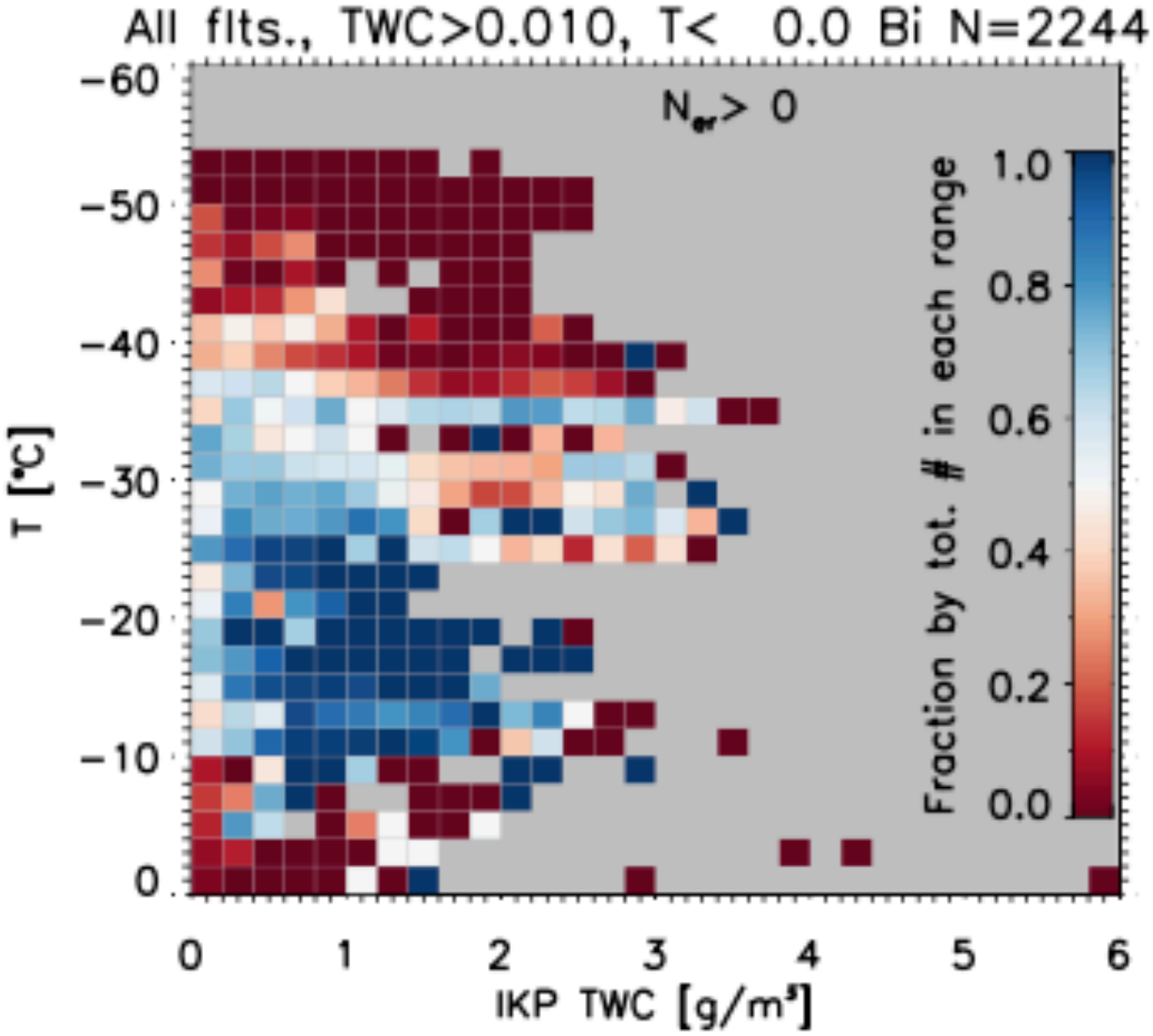
Automated technique for identifying D_1 and D_2

- D_1 = ~50-150 μm
- D_2 = ~200-500 μm

How do environmental conditions for vary for uni & bi modal PSDs?

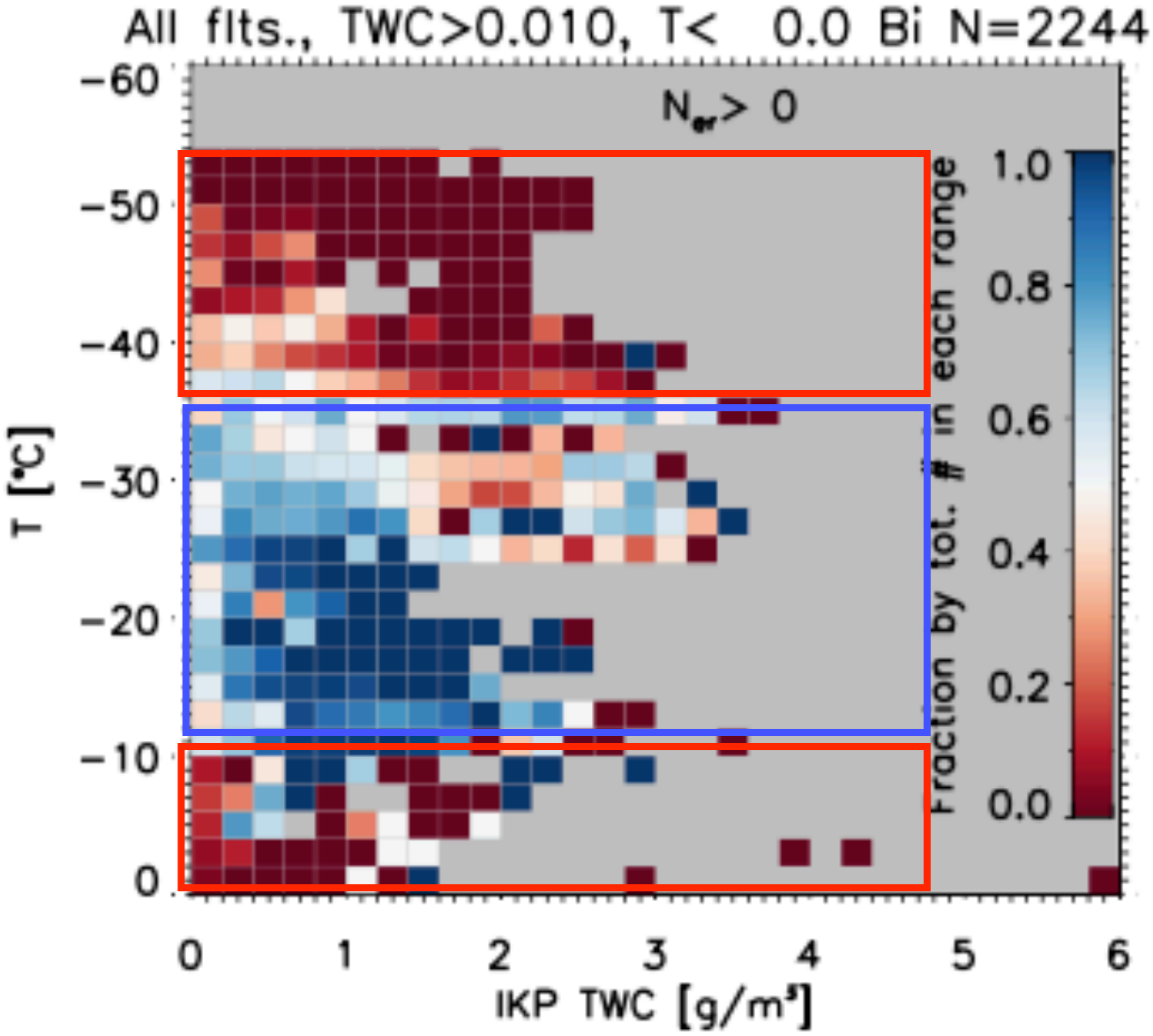


How do environmental conditions for vary for uni & bi modal PSDs?



- N_{Bi}/N_{Bi+Uni} in "*each T&TWC range*"
- White, Uni = Bi
- Red, Uni > Bi
- Blue, Uni < Bi

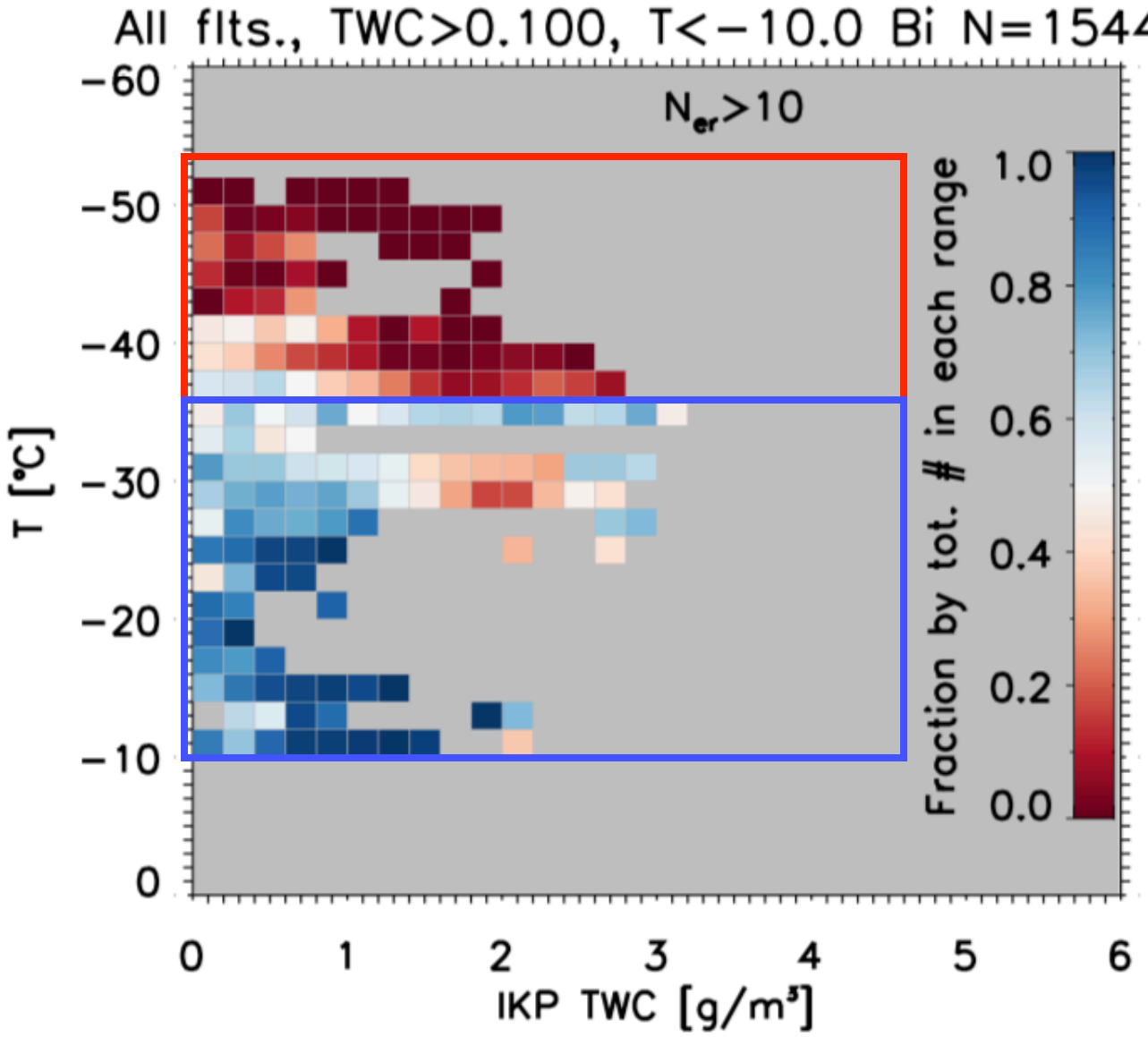
How do environmental conditions for vary for uni & bi modal PSDs?



- N_{Bi}/N_{Bi+Uni} in "*each T&TWC range*"
- White, Uni = Bi
- Red, Uni > Bi
- Blue, Uni < Bi

- Larger Uni @ *T*<-36 & *T*>-10
- Larger Bi @ -36 < *T* < -10 with exception @ *TWC* = ~2.0 & *T*=-30

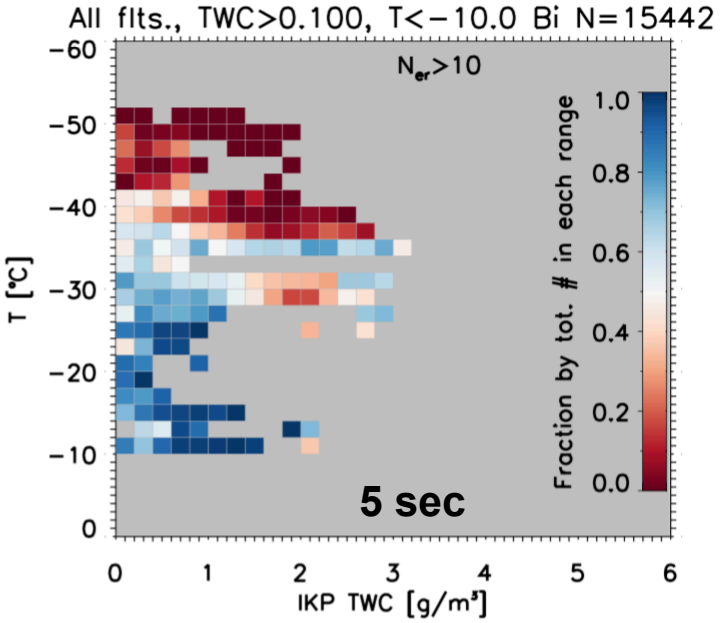
How do environmental conditions for vary for uni & bi modal PSDs?

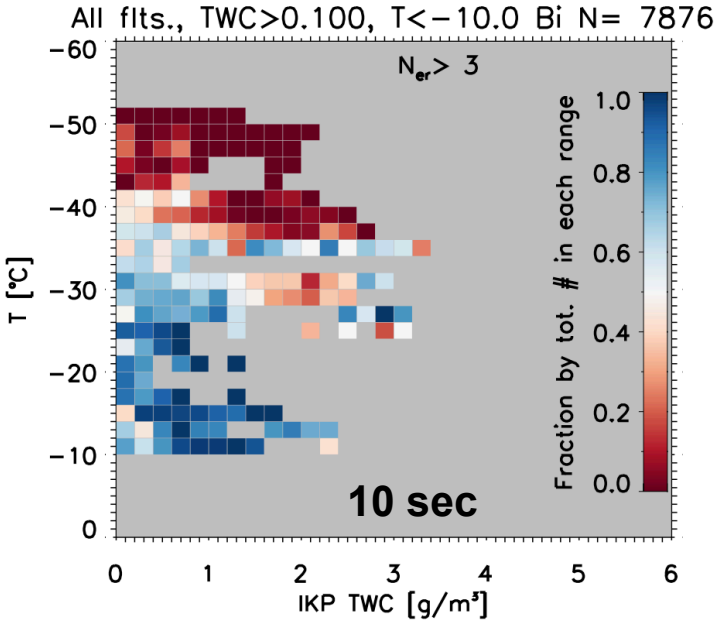


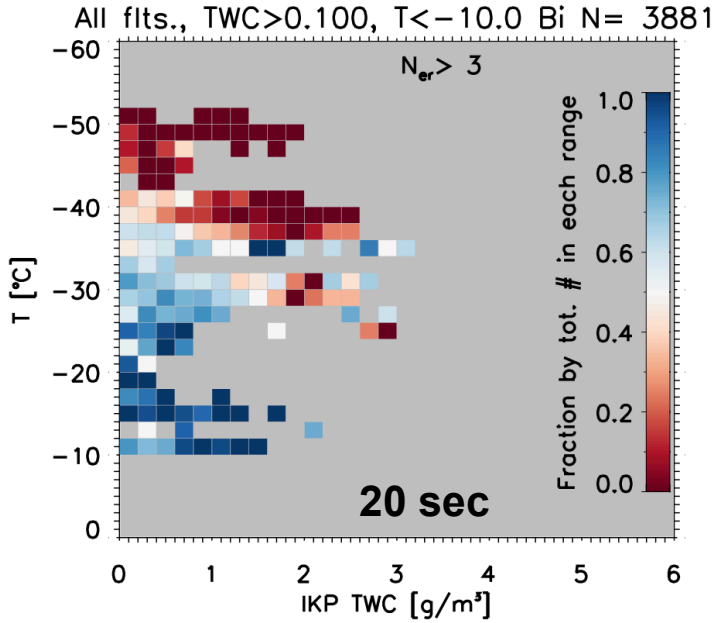
- Diff. *T* & *TWC* thresholds
- *T* < -10, *TWC* > 0.1
- Total 15442 5 sec
- # of sample > 10 in each *T*&*TWC* range (N_{er})

- Larger Uni @ *T*<-36
- Larger Bi @ -36 < *T* < -10 with exception @ *TWC* = ~2.0 & *T*=-30

How do environmental conditions for vary for uni & bi modal PSDs?



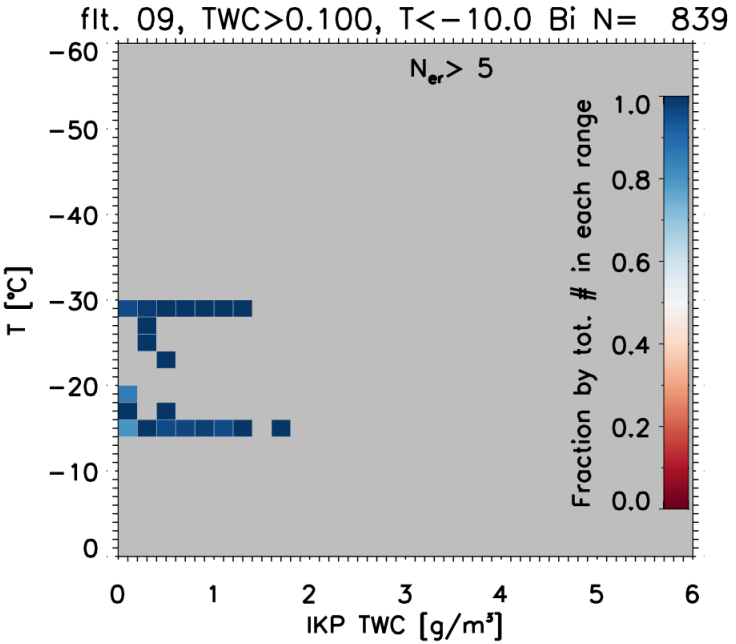


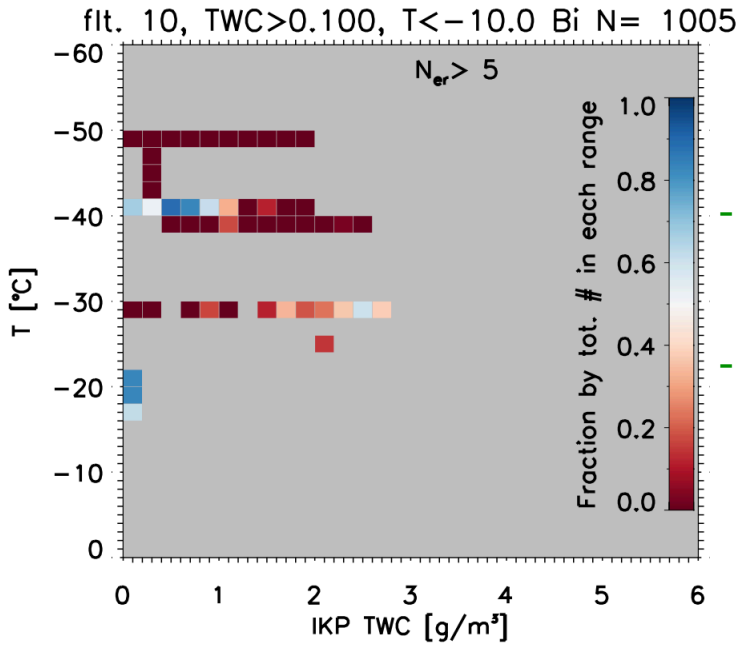


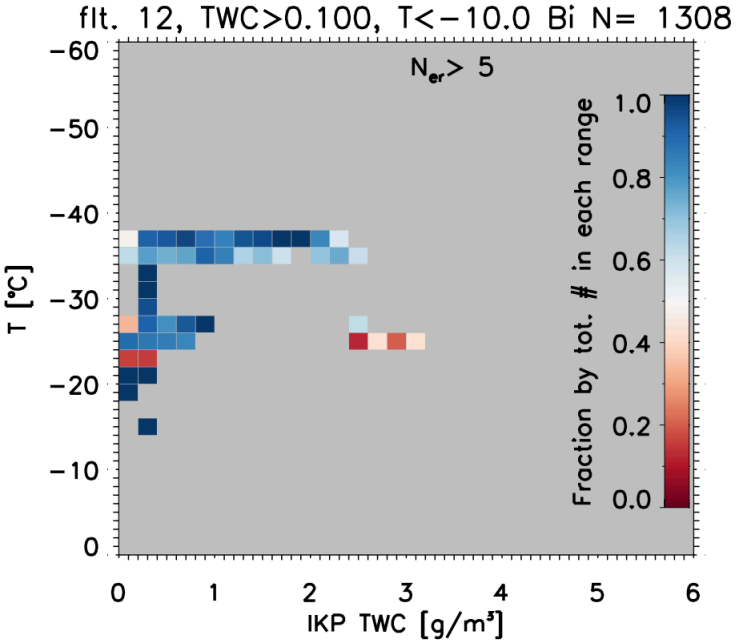
- **Invariant with diff. time resolution**
- **Larger scale feature**

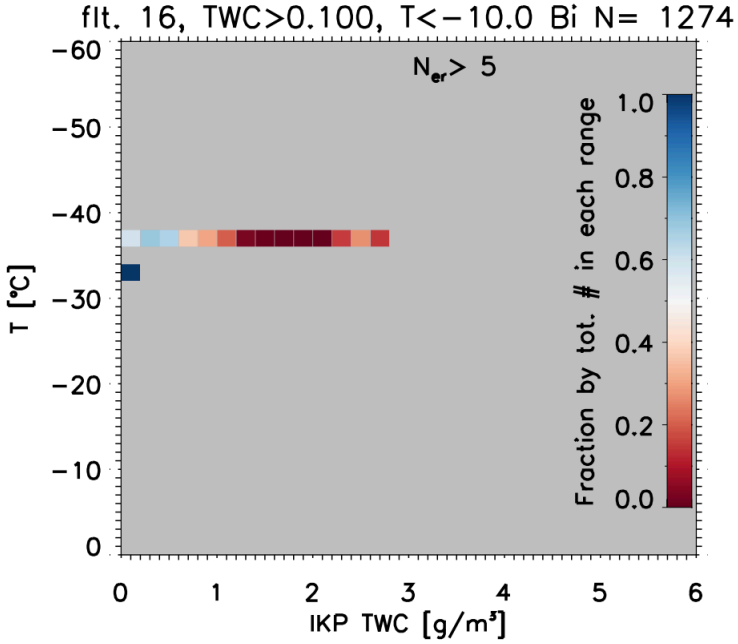
- **Larger Uni @ *T*<-36**
- **Larger Bi @ -36 < *T* < -10 with exception @ *TWC* = ~2.0 & *T*=-30**

How do environmental conditions for vary for uni & bi modal PSDs?



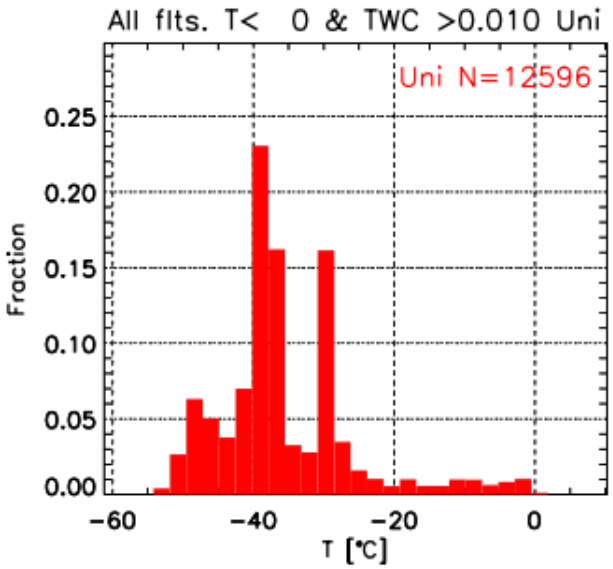


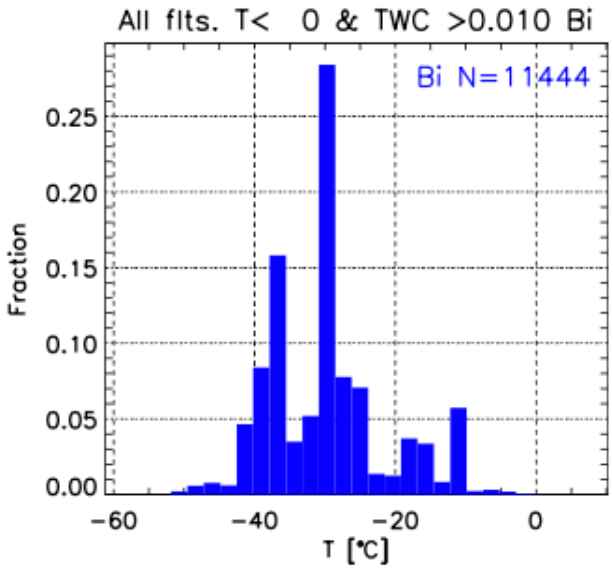




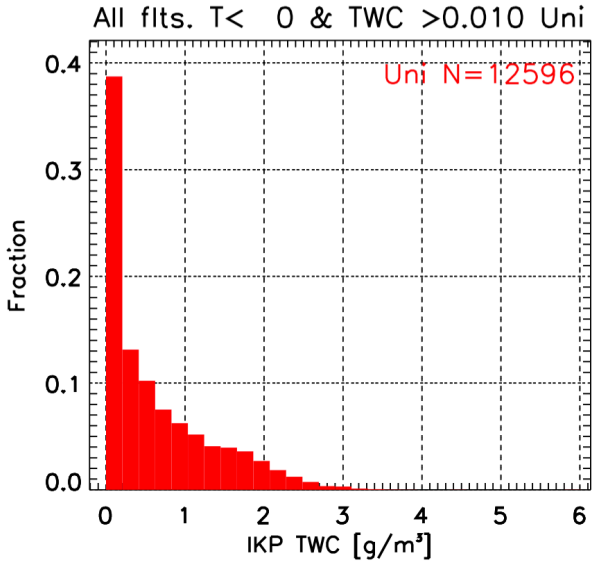
- Different feature for different flight
- Dependence on *T*

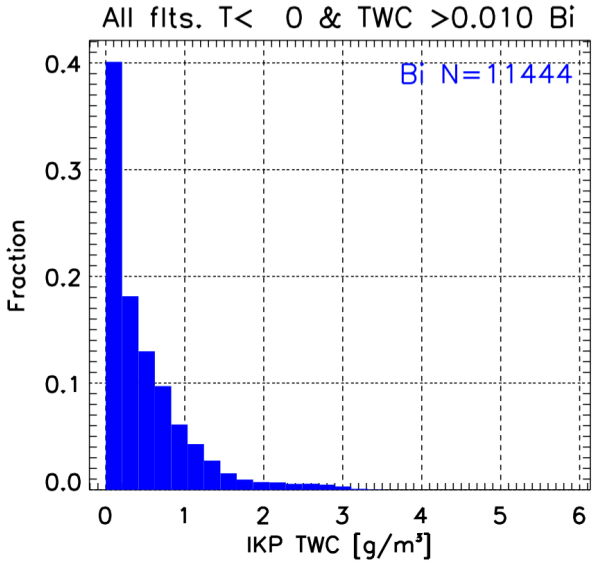
How do environmental conditions for vary for uni & bi modal PSDs?



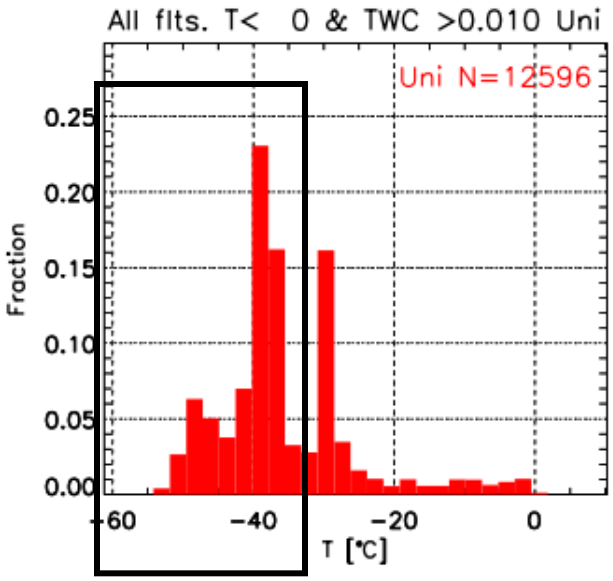


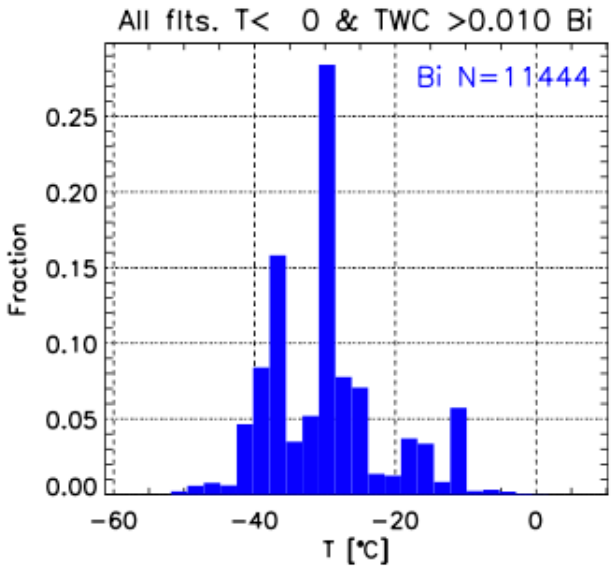
- **Left column: Uni**
- **Right column: Bi**
- **Upper panel: T**
- **Lower panel: TWC**





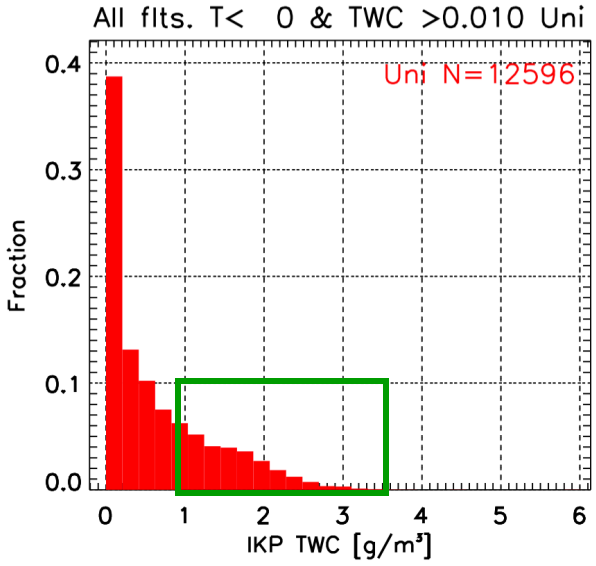
How do environmental conditions for vary for uni & bi modal PSDs?

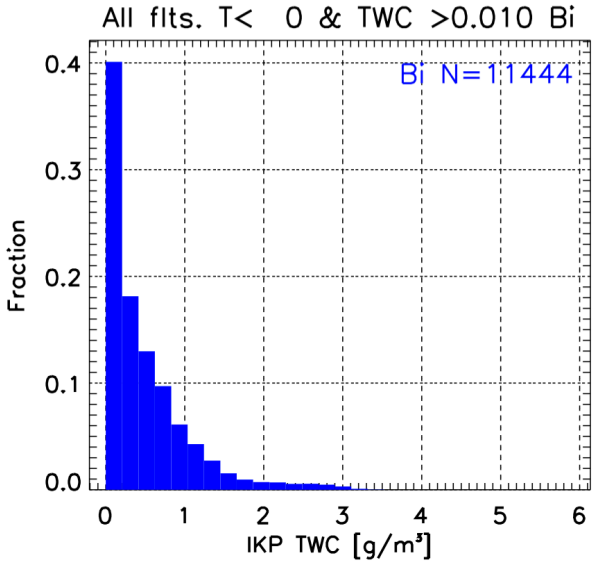




- **Left column: Uni.**
- **Right column: Bi.**
- **Upper panel: T**
- **Lower panel: TWC**

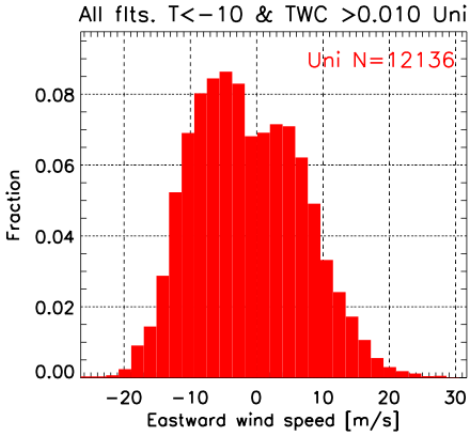
- **Unimodality is more frequent at lower T**

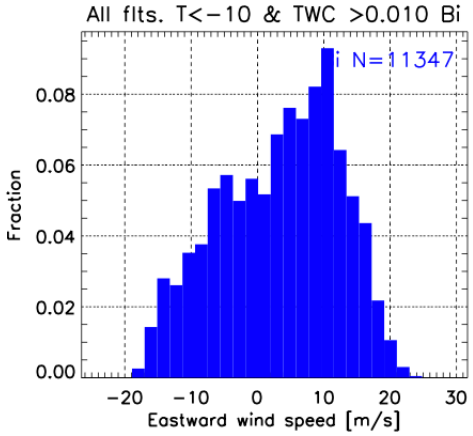


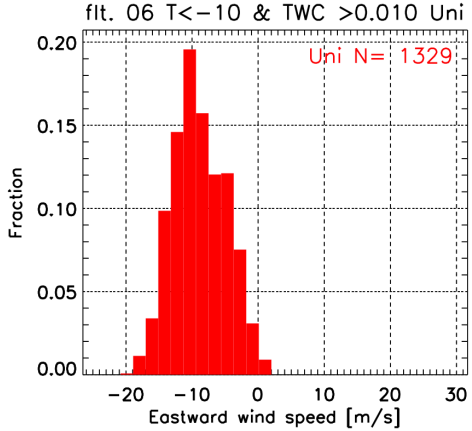


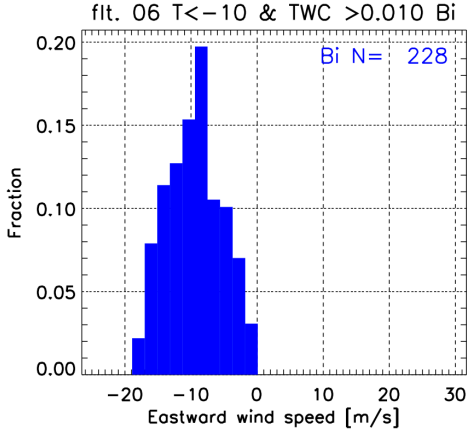
- **Unimodality is more frequent at higher TWC**

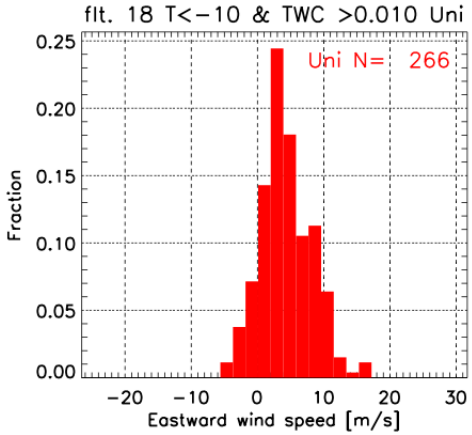
How do environmental conditions for vary for uni & bi modal PSDs?

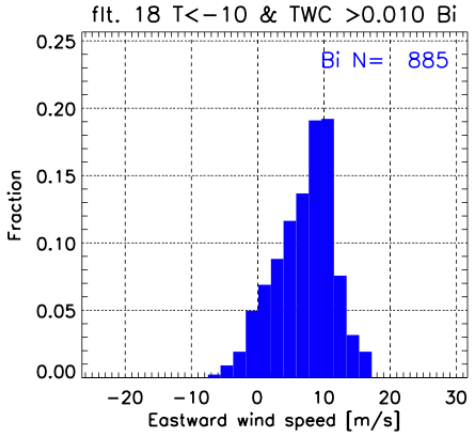












- No universal environmental condition (except *T&TWC*) governs bimodality (so far…)

- Left column: Uni.
- Right column: Bi.

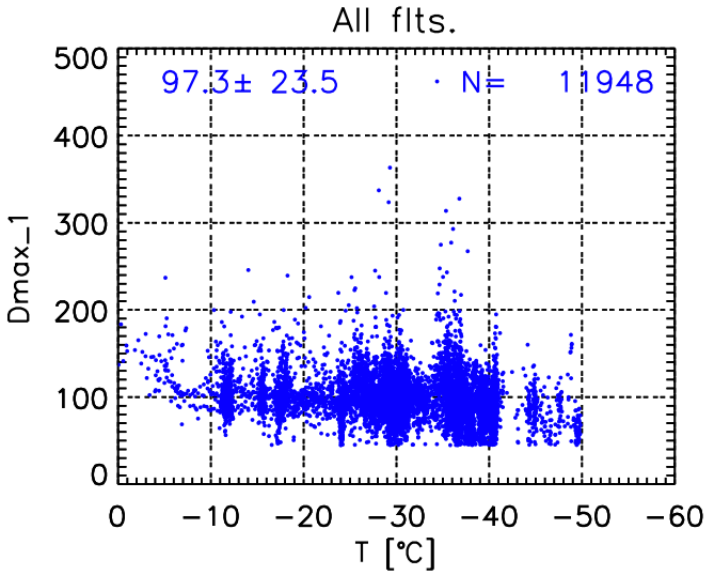
- Upper panel: All flts.
- Middle panel: flt. 6
- Lower panel: flt. 18

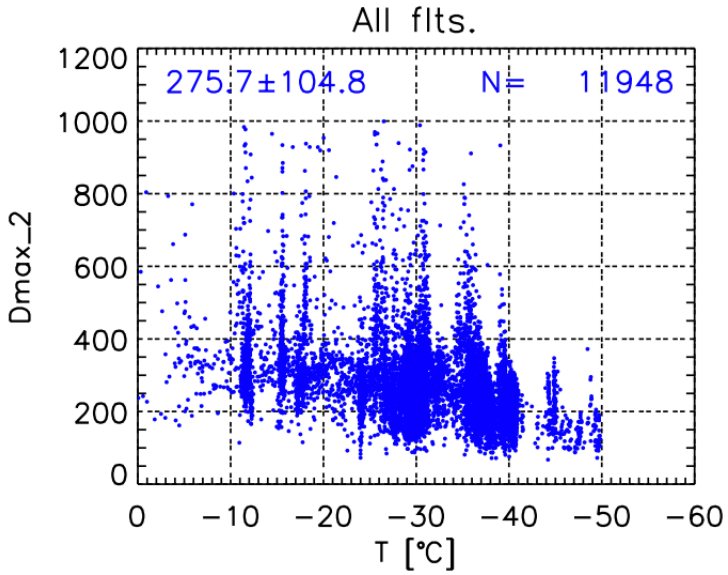
- All flts. (upper) shows diff. b/n uni and bimodality by eastward wind speed

- But flts. 6 (middle) & 18 (lower) show that it is sample oriented feature (where & when sampled)

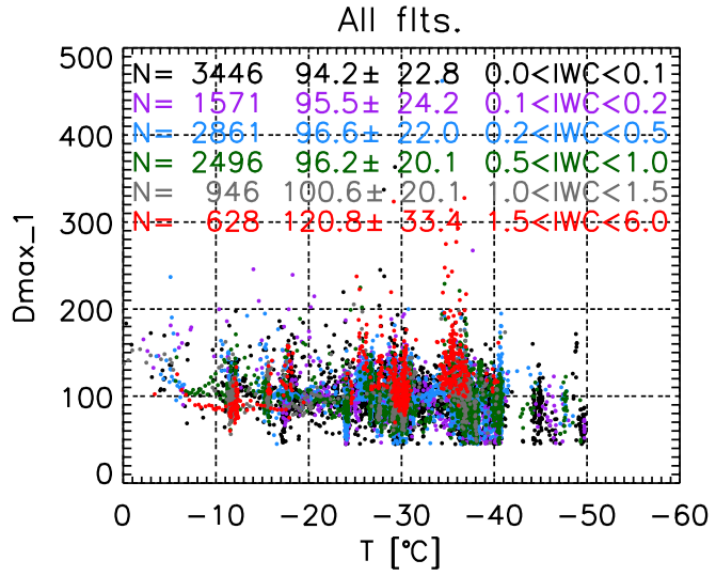
- Flt. 18 shows more distinct feature than flt. 6

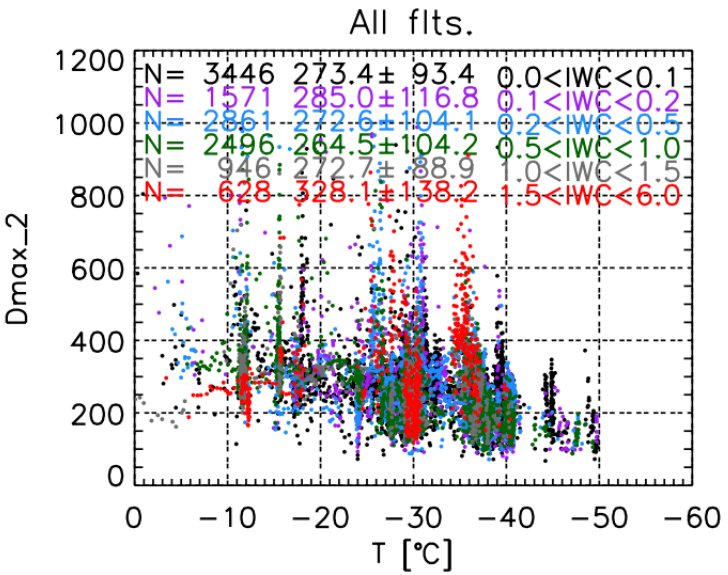
- **Parameters govern Bimodality**



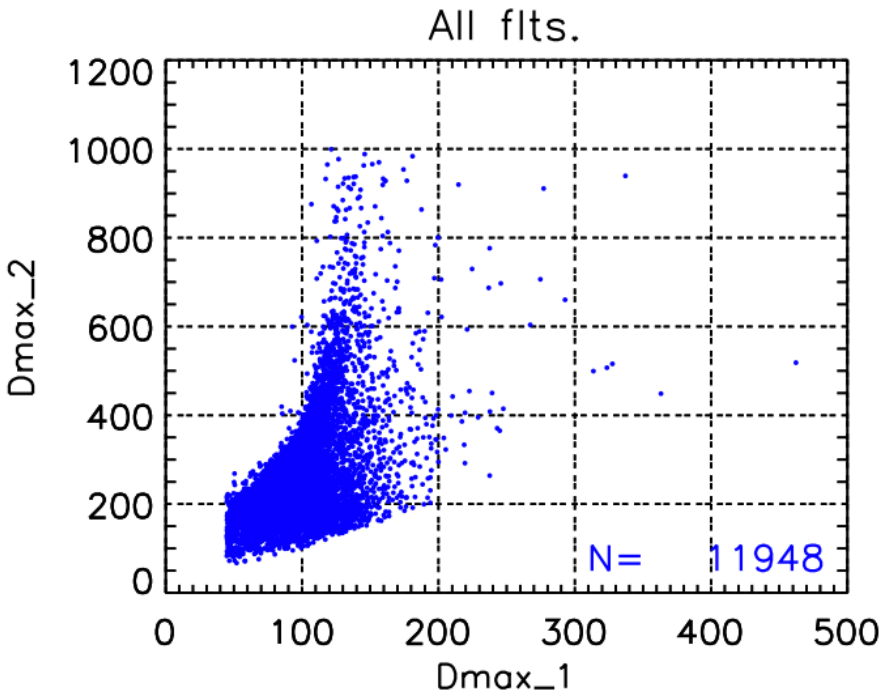


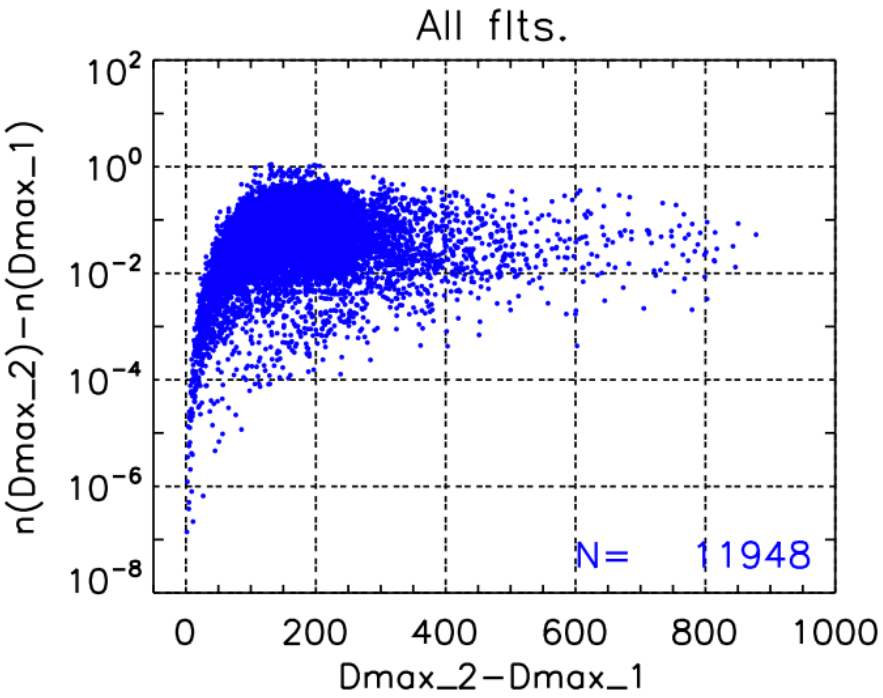
- ***D_1* & *D_2* decrease with *T* decrease**
- ***D_1* & *D_2* increase with *IWC* increase**





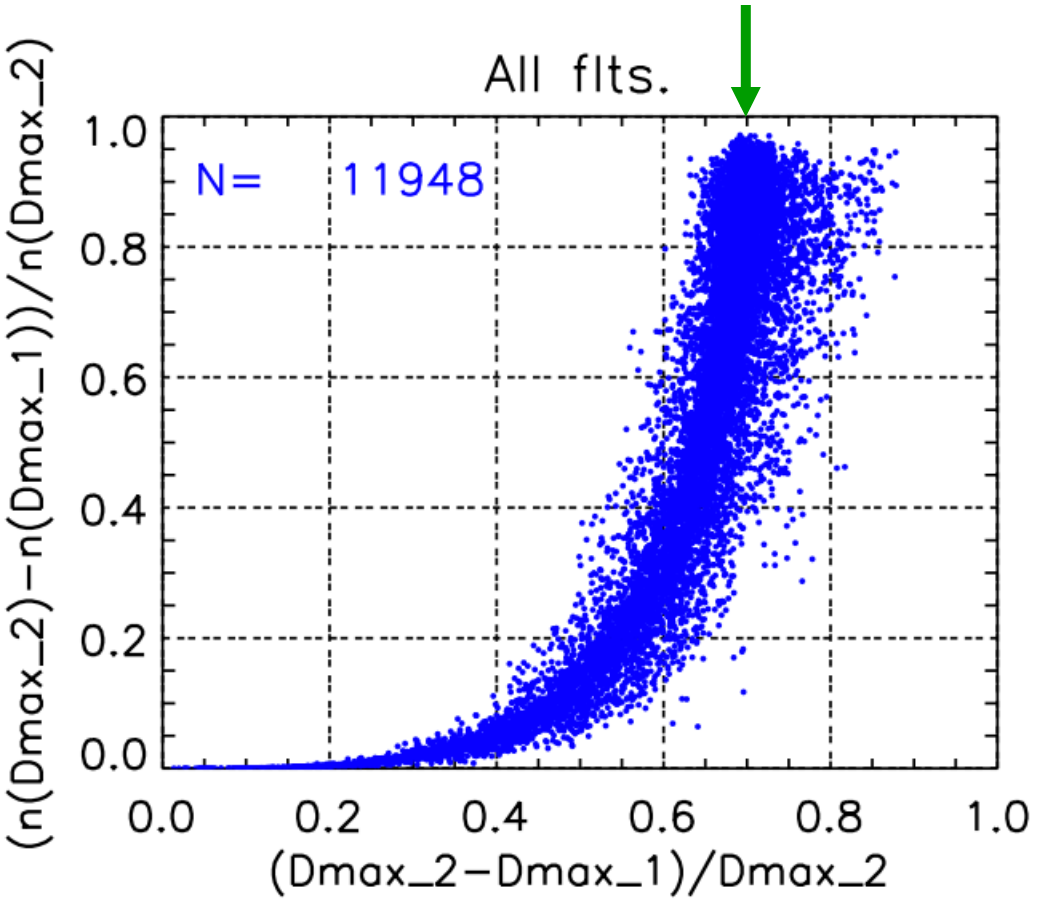
- **Parameters govern Bimodality**





- Some correlation between D_1 & D_2
- Some correlation between D_2-D_1 and $n(D_2)$-$n(D_1)$
- *It's not clear due to difference in scale!*
- *Bimodality occurs in both small and large sizes*

Parameters govern Bimodality



- ***Normalization makes it simple!***

- **Normalized D difference**

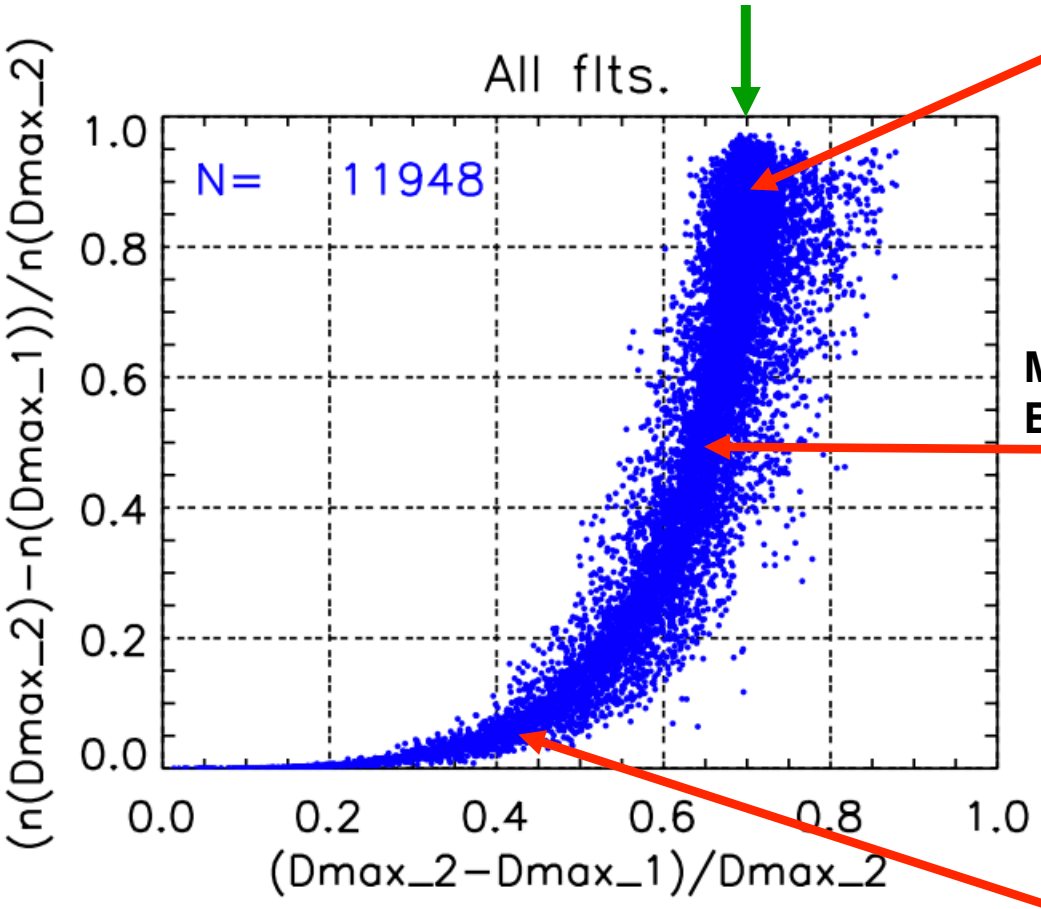
$$D\downarrow 2 - D\downarrow 1 \,/ D\downarrow 2$$

- **vs.**
- **Normalized concentration difference**

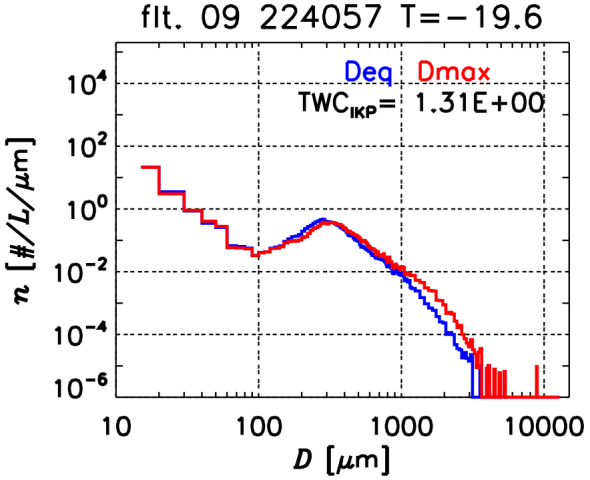
$$n(D\downarrow 2\,) - n(D\downarrow 1\,)/n(D\downarrow 2\,)$$

- **As normalized *D* difference increase, normalized concentration difference converges to ~0.7**

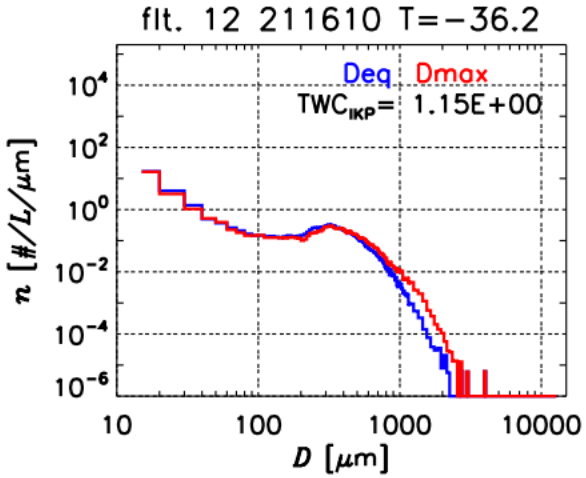
- **Parameters govern Bimodality**



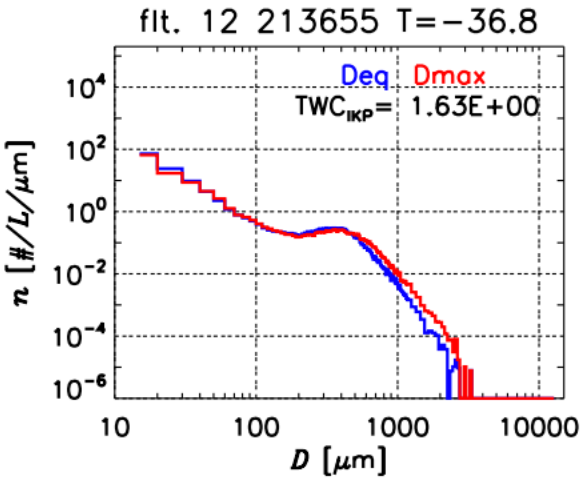
Strong Bimodality



Moderate Bimodality



Weak Bimodality



- **For strong bimodality, D_1 is 70% smaller than D_2**

Summary

- IWC-MMD can be either positively or negatively correlated in high IWC regions
  - SD characteristics different for varying regions
  - No complete explanation, but system age and location offer some separation of cases
  - Are SDs in these regions similar to SDs in non high-IWC conditions?
- Making progress in characterizing multi-modal distributions and determining where they occur
- Extending to investigate radiative properties

- **Bimodality of PSD shows dependence on *T* & *TWC***
- **Stronger dependence on *T***

- **D_1 & D_2 decease with *T* decrease**
- **D_1 & D_2 increase with *TWC* increase**

- **D_1=97±24 μm, D_2=276±105 μm @ T < 0, D_{max}**
- **D_1=90±22 μm, D_2=254±93 μm @ T < 0, D_{eq}**

- **Normalized dimensions give better view to understand PSD bimodality**
- **For strong bimodality, D_1 is 70% smaller than D_2**

- **Further analysis with the normalized dimensions will be made**