Characterizing the vertical distribution of aerosols using multiwavelength lidar data: *Preliminary* results from the Combined HSRL And Raman lidar Measurement Study (CHARMS) at SGP

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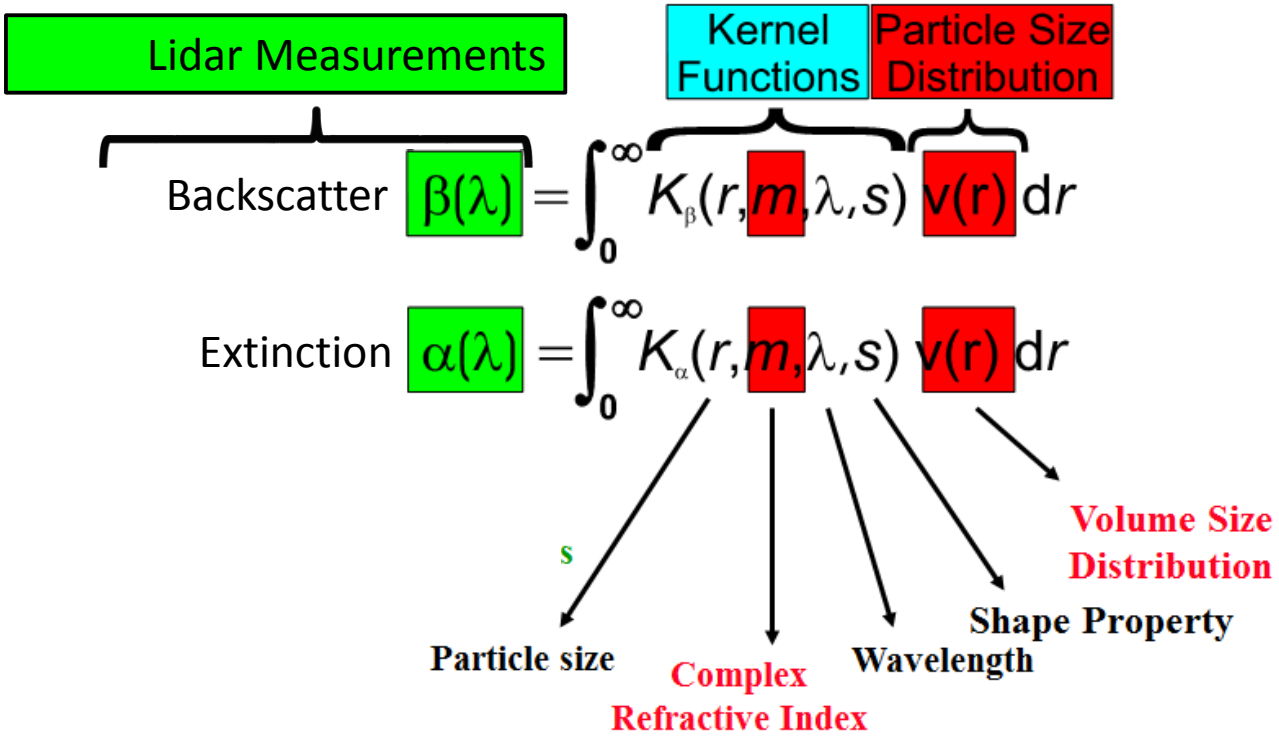
Motivation and Objective

- Aerosol optical and microphysical properties are required to:
  - Impacts on radiation
  - Aerosol-cloud interactions
  - Develop and evaluate model parameterizations
- Currently, ARM measures and/or derives aerosol properties at the surface and column average properties but does not operationally measure vertical properties
- Multiwavelength lidar retrievals
  - Potential for operational aerosol microphysical and optical properties
  - Algorithms developed by NASA LaRC for future NASA ACE satellite mission may be suitable for DOE ARM use
    - Have been applied to numerous NASA LaRC airborne HSRL 3+2 datasets

- **CHARMS Objective: Investigate use of combined ground-based Raman and High Spectral Resolution Lidar (HSRL) measurements to improve ARM observational capability of aerosols and clouds**
  - July 18 to September 30 2015 at SGP

Tikhonov Advanced Regularization Algorithm (TiARA) Multiwavelength Lidar Aerosol Retrievals

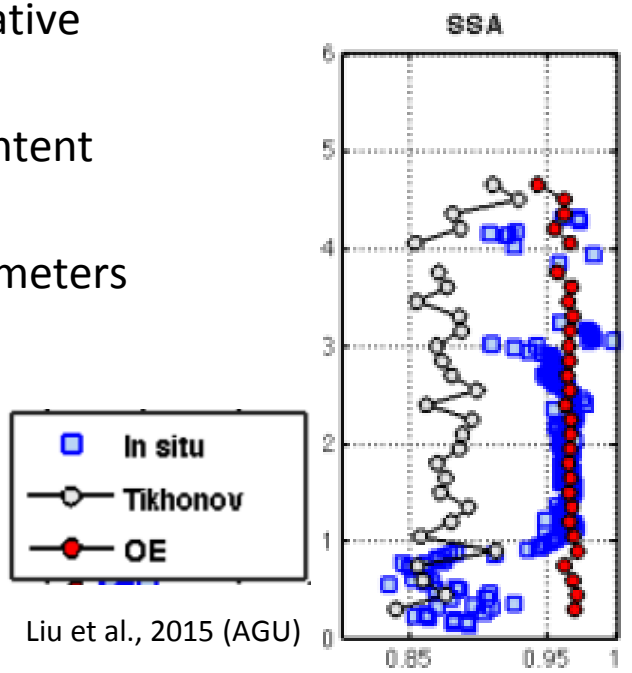
- **Input**: aerosol backscatter (3λ) and extinction (2λ): "3β+2α" profiles
- Data inversion with regularization (Müller et al., 1998,1999,2001; Veselovskii et al., 2002)
  - Assumes spherical particles; nonspherical particles retrievals are under investigation



- **Outputs**: effective radius (total, fine, coarse), concentration (number, surface, volume), scattering, absorption coefficients

Multiwavelength Lidar Aerosol Retrieval Outlook

- Tikhonov regularization: absorption biased high relative to in situ measurements
- Burton et al. (AGU – 2015) study on information content in lidar measurements alone
  - Good retrievals of size and concentration parameters
  - Have only limited ability to produce accurate absorption



Liu et al., 2015 (AGU)

- **Higher accuracy in absorption measurements requires additional constraints**
  - Arrange and Average (Chemyakin et al., 2015) adds additional constraint/assumption on size distribution (monomodal)
  - Optimal Estimation retrieval methodology also being pursued at NASA LaRC
    - Leverage retrieval of aerosol type
    - Add other measurements (ex. polarimeter, Sun photometer) as constraints

CHARMS Merged HSRL and Raman Lidar Datasets

Measurements (3β+2α)

SGP Raman lidar:

- Aerosol backscatter (355nm)
- Extinction (355nm)
- *Depolarization (355nm)

Univ. Wisconsin HSRL

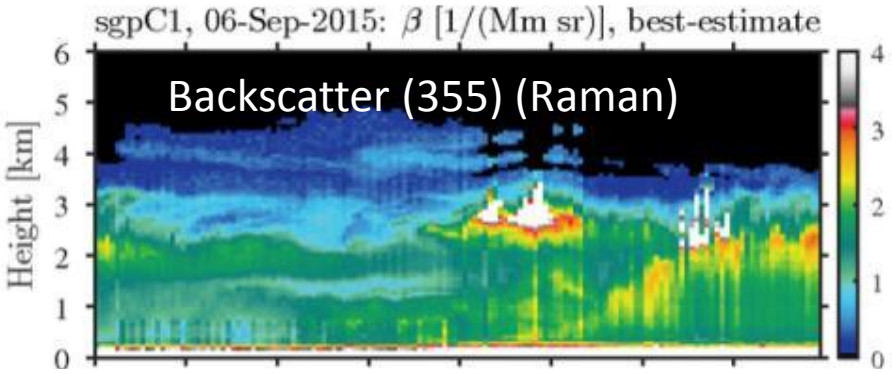
- Aerosol backscatter (532, 1064nm)
- Extinction (532 nm)
- *Depolarization (532 nm)

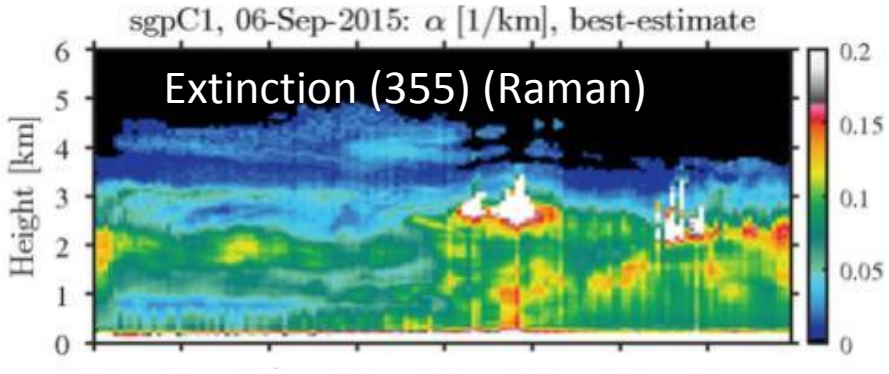
*Aerosol type classification (Burton et al., 2012, 2013, AMT)

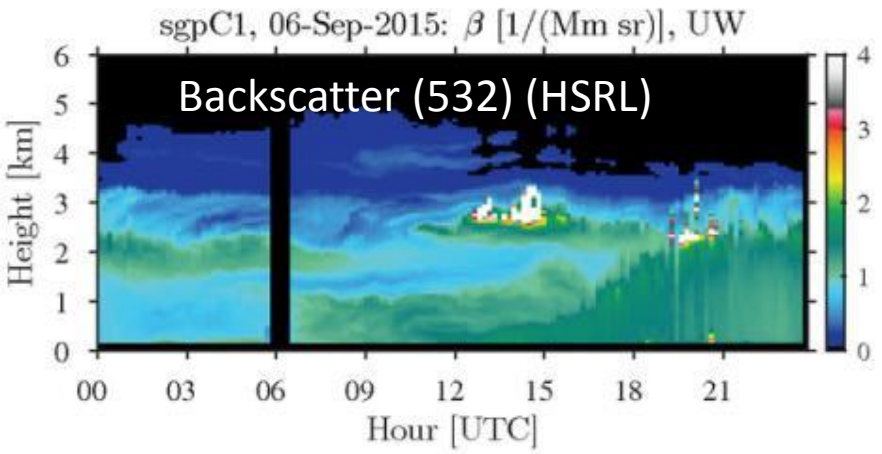
- Process extinction/backscatter from both instruments consistently using the FEX algorithm (Thorsen et al.; Thorsen and Fu 2015)
- 10min, 60m vertical resolution (120m for the microphysical retrievals)
- Images of results:
  - http://www.tylerthorsen.com/bagohsrlfex_charms/

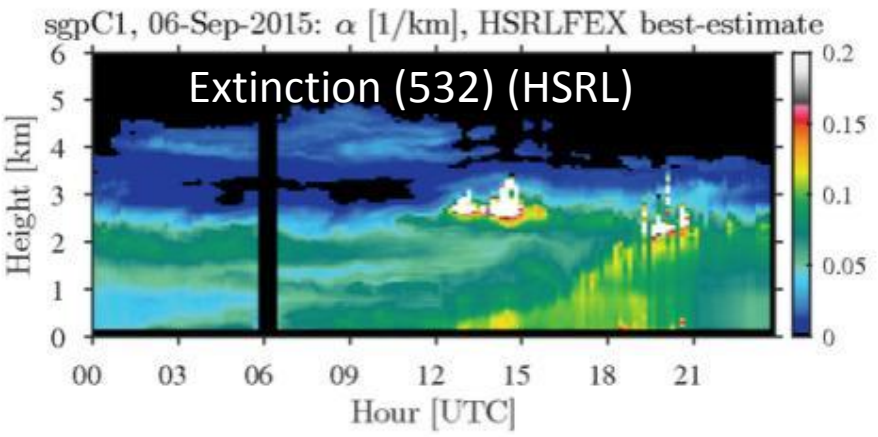
CHARMS Processing

- **All images and results that follow are preliminary!**
- Some artifacts in Raman (mostly) and HSRL data due to temperature and alignment fluctuations
- SGP Raman lidar performance improved after CHARMS and now comparable to ENA Raman lidar



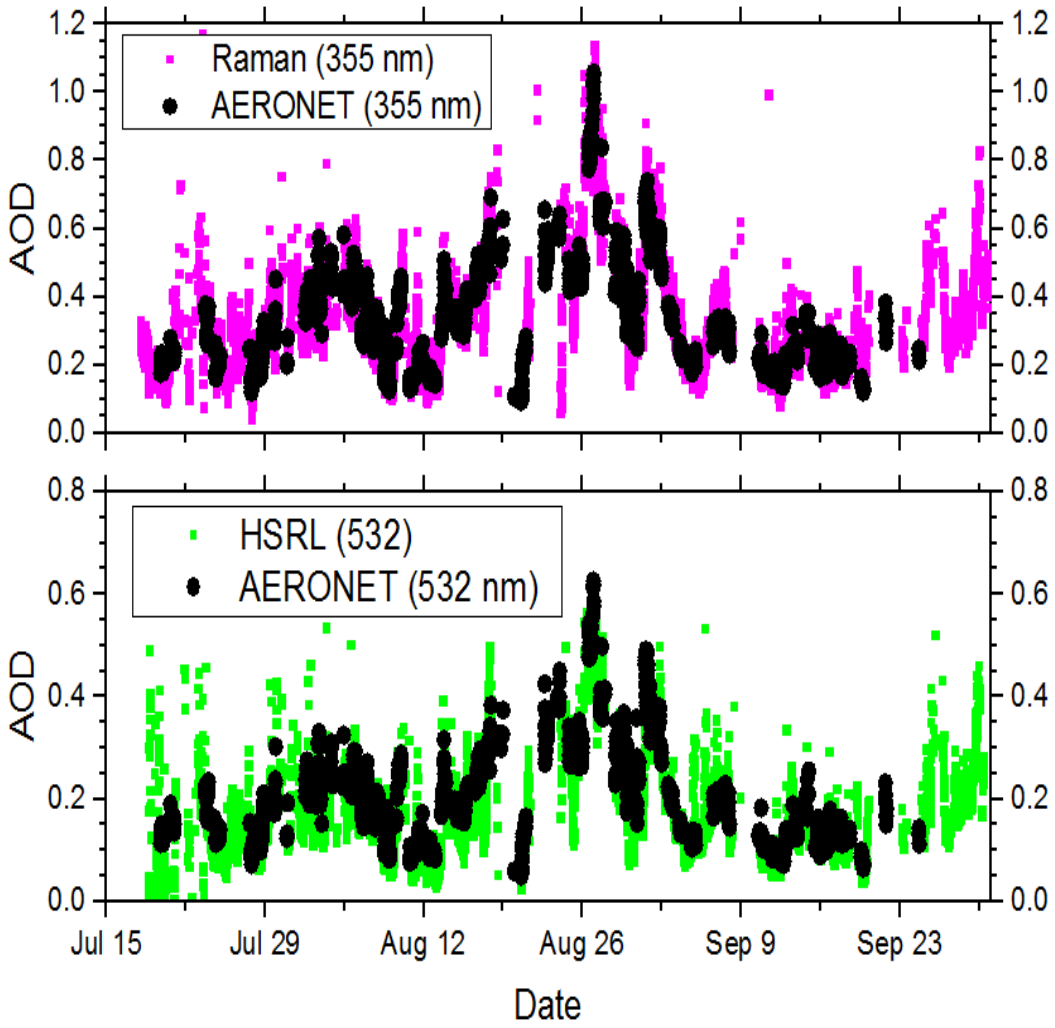


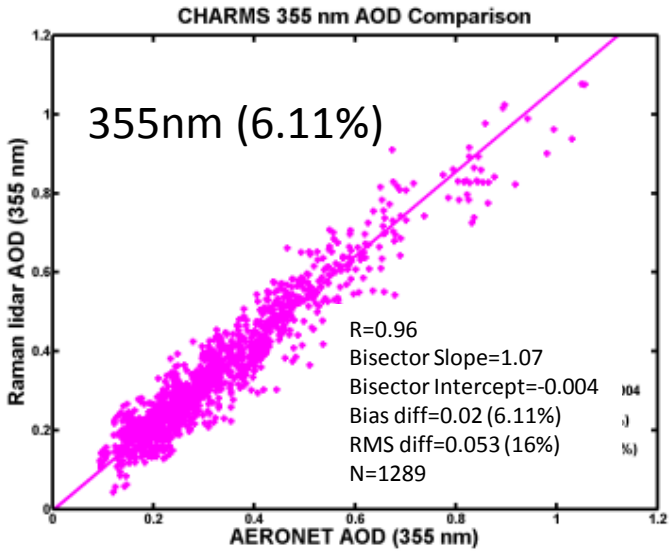


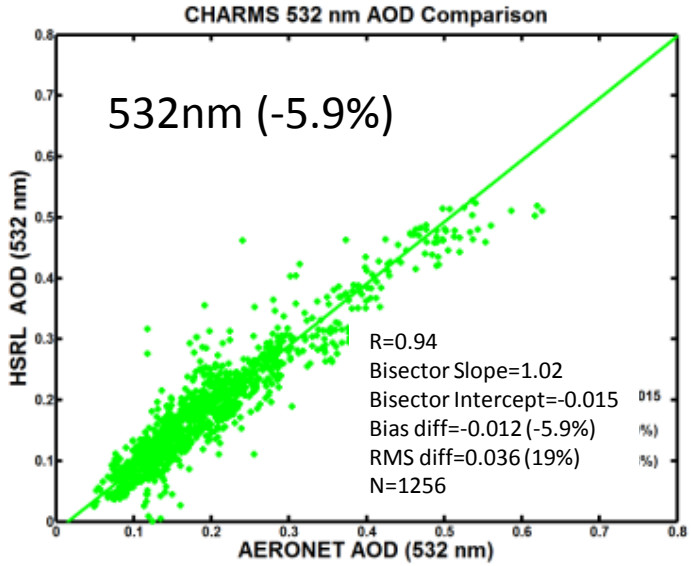


Good agreement between CHARMS and AERONET Aerosol Optical Depth (AOD)

Aerosol Optical Depth computed using extinction profiles at 355 and 532



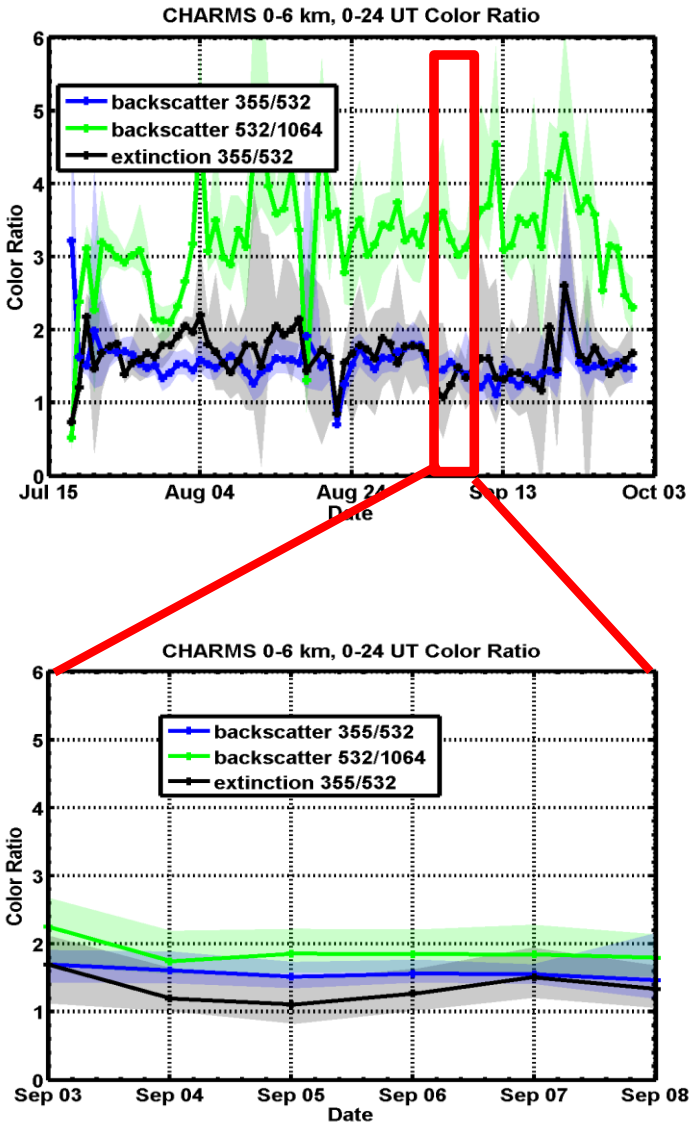




Difficulty in producing accurate 1064 nm aerosol backscatter profiles has delayed retrievals

Microphysical retrievals performed for Sept 3-7

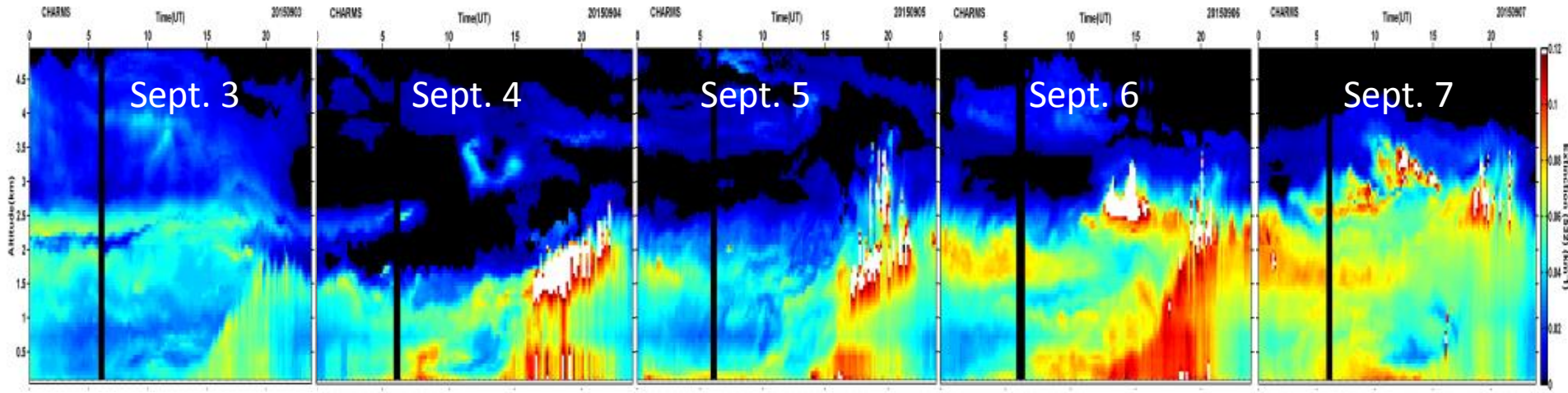
- Aerosol backscatter color ratio (532/1064) was much higher (>3) than expected
  - 1064 nm aerosol backscatter was too low
  - Difficulty in calibration the UW HSRL 1064nm aerosol backscatter (see Eloranta poster)



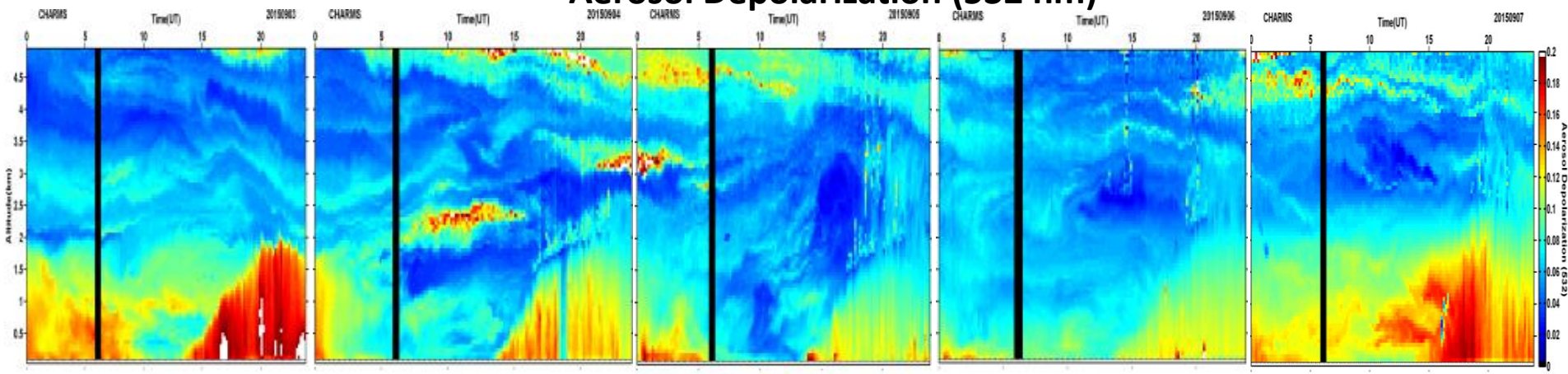
CHARMS data used for aerosol retrievals currently limited to test period (Sept. 3-7)

- Note variability in both aerosol loading (extinction) and type (aerosol depolarization)
- High depolarization in the afternoon (>10%: too high for reliable microphysical retrievals)

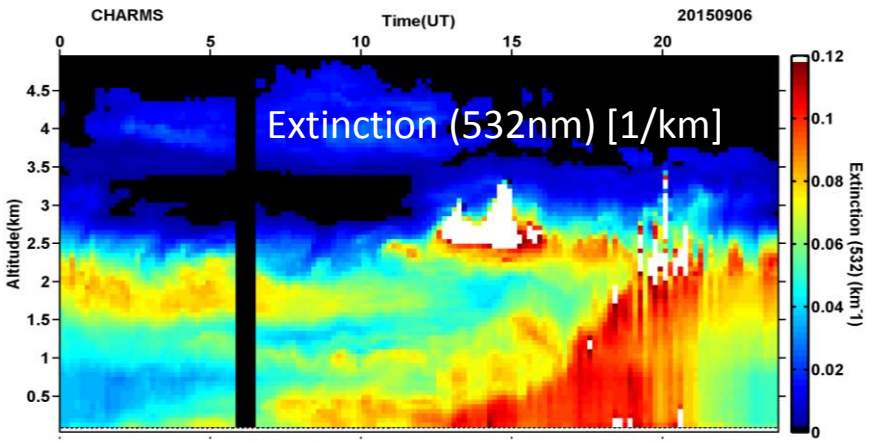
Aerosol Extinction (532 nm)

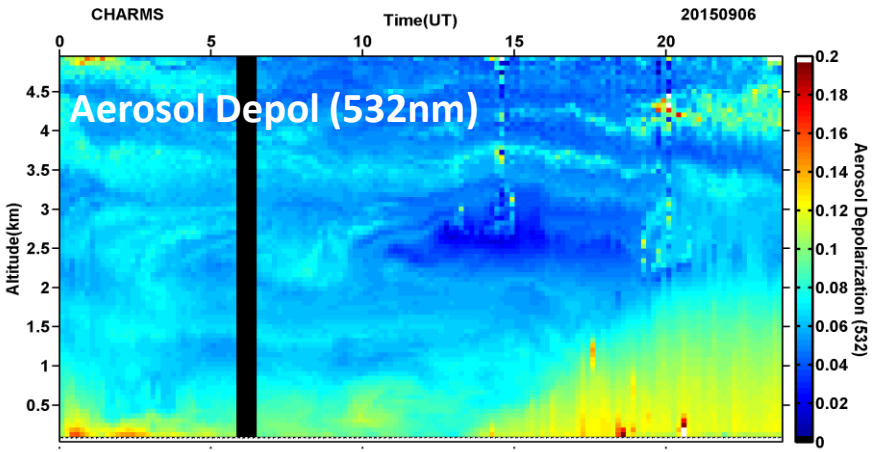


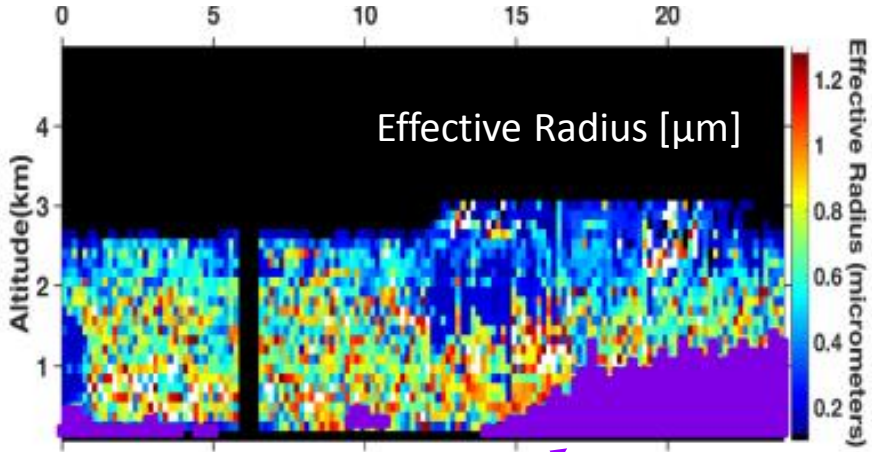
Aerosol Depolarization (532 nm)

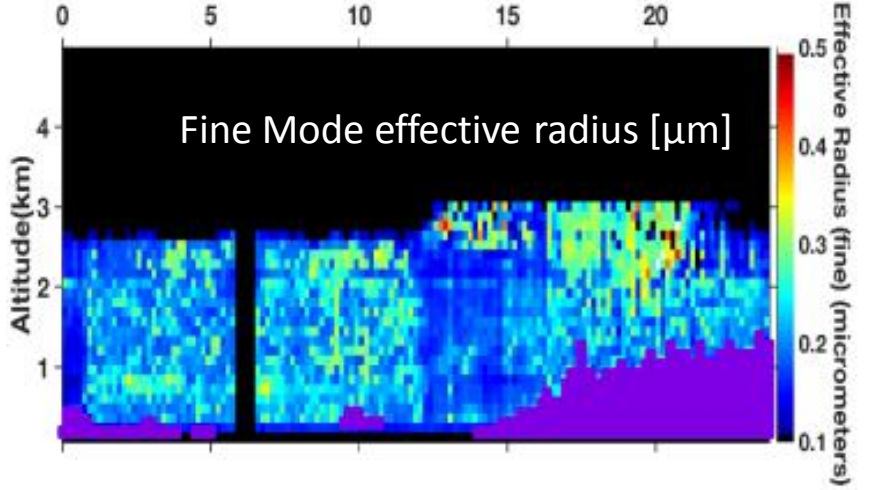


Tikhonov Advanced Regularization Algorithm (TiARA) - Retrieval Results (ex. Sept. 6)



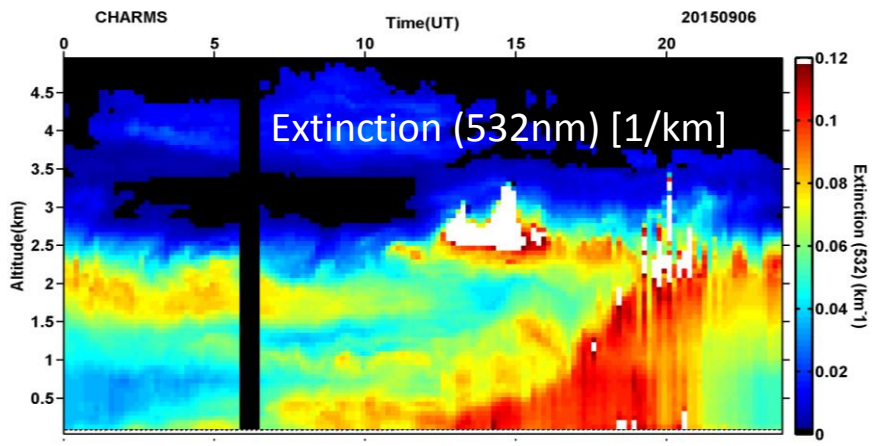


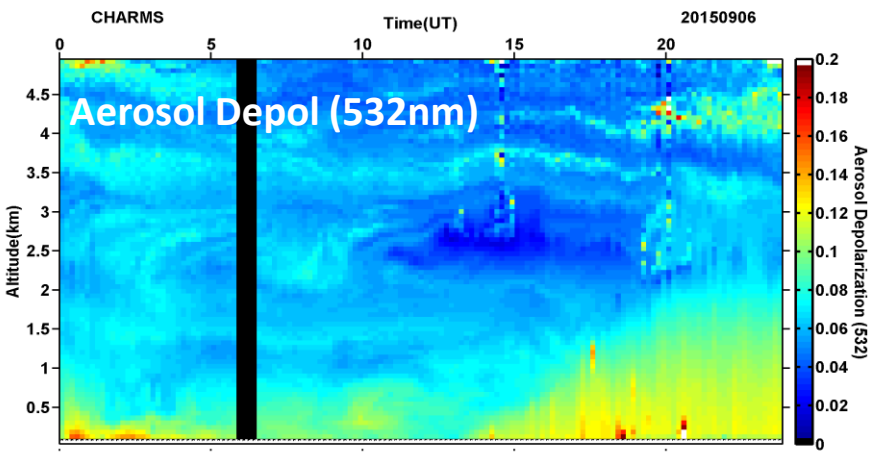


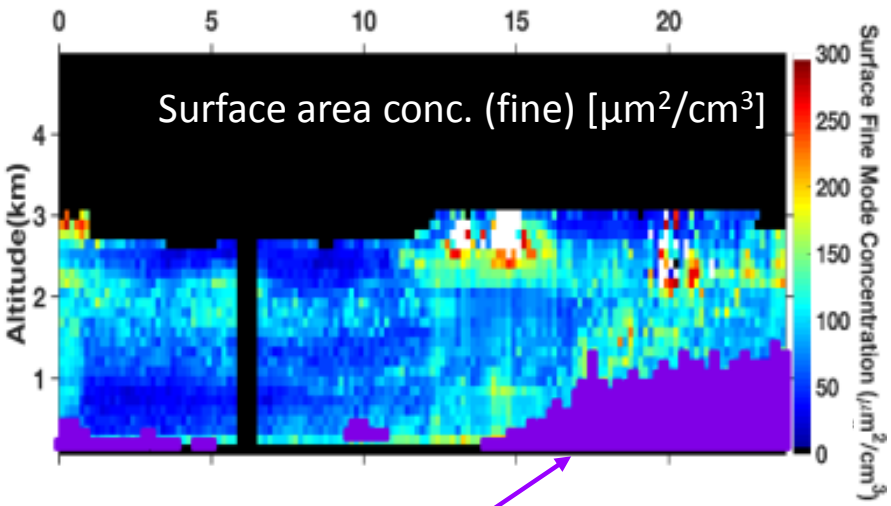


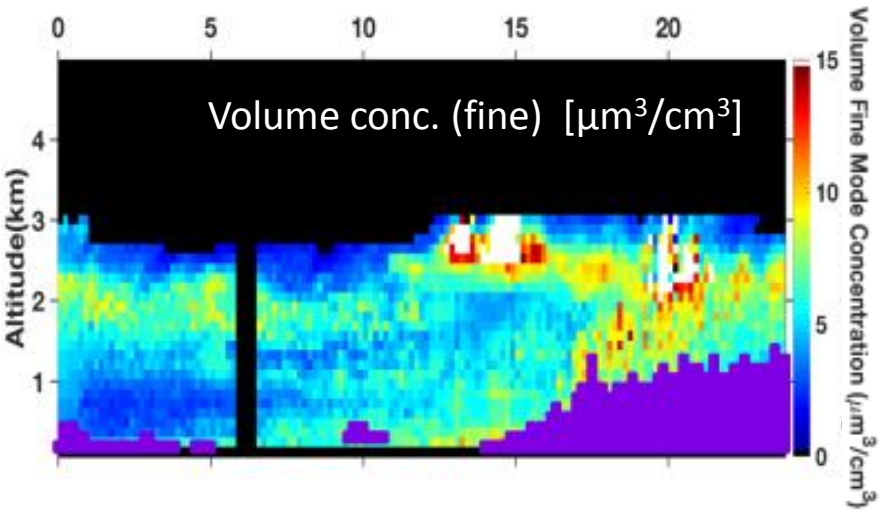
- Depolarization > 10% → retrievals unreliable
- TiARA expected to give good performance for size and concentration retrievals

Tikhonov Advanced Regularization Algorithm (TiARA) - Retrieval Results (ex. Sept. 6)









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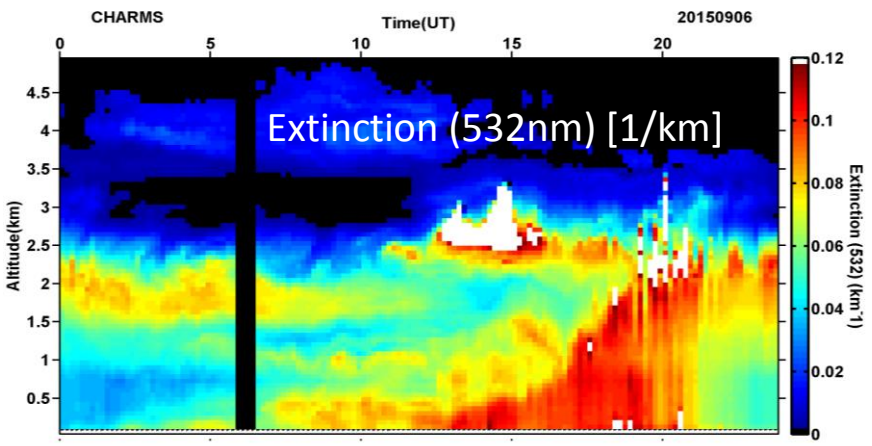
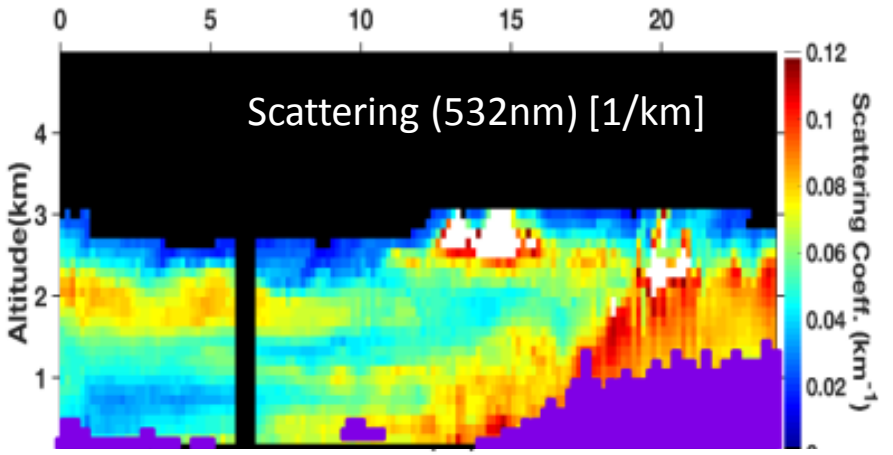
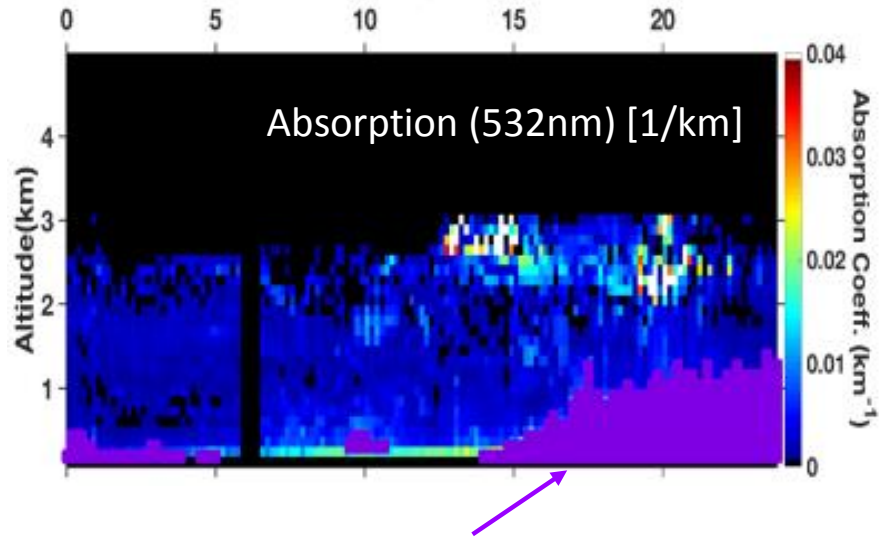
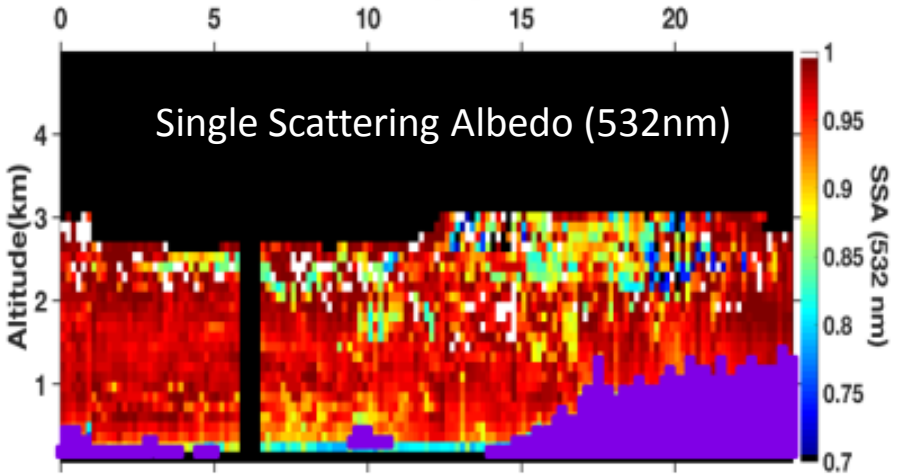
Arrange and Average Algorithm (A&A) - Retrieval Results (ex. Sept. 6)



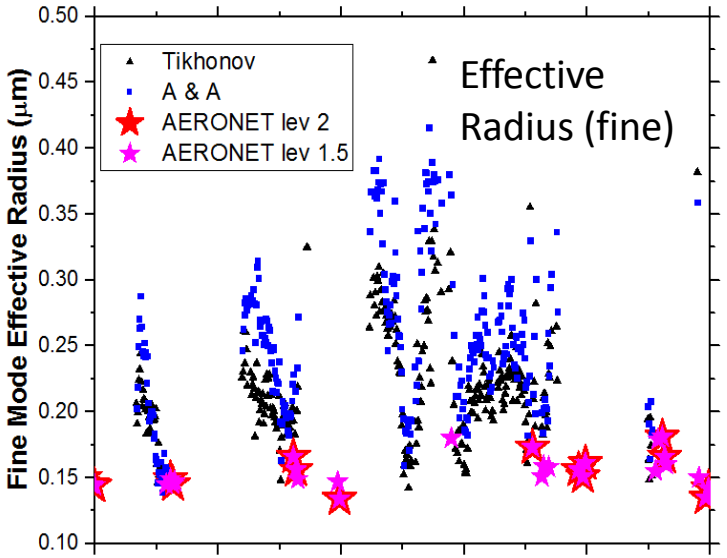


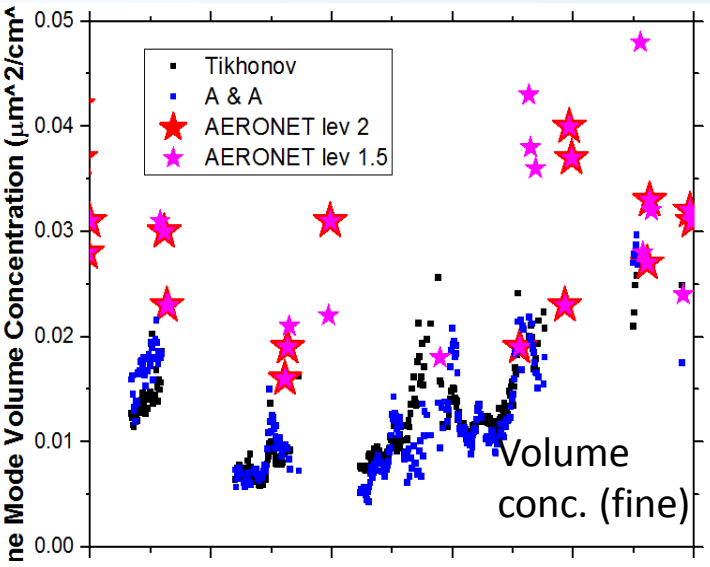


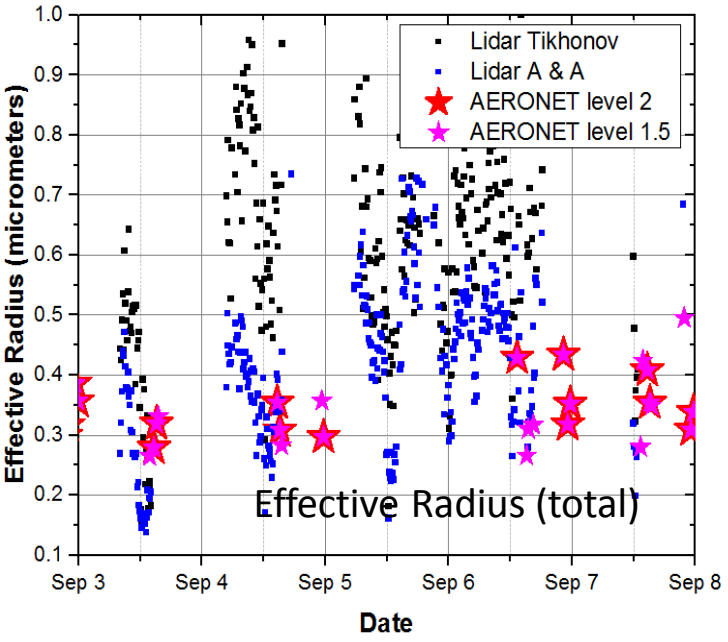


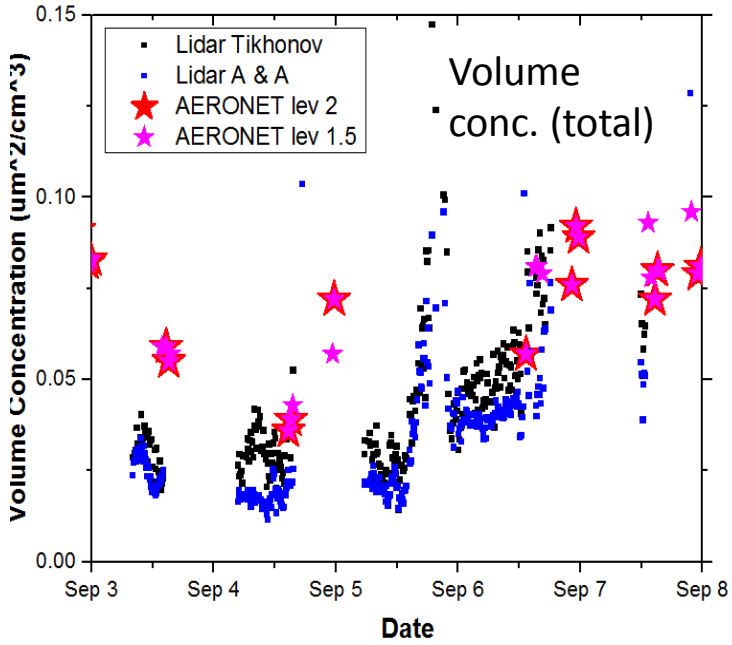
- Depolarization > 10% → retrievals unreliable
- A&A expected to give better performance for absorption retrievals

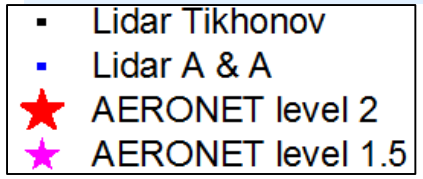
Comparisons of Column Averages with AERONET - Effective Radius and Volume Concentration







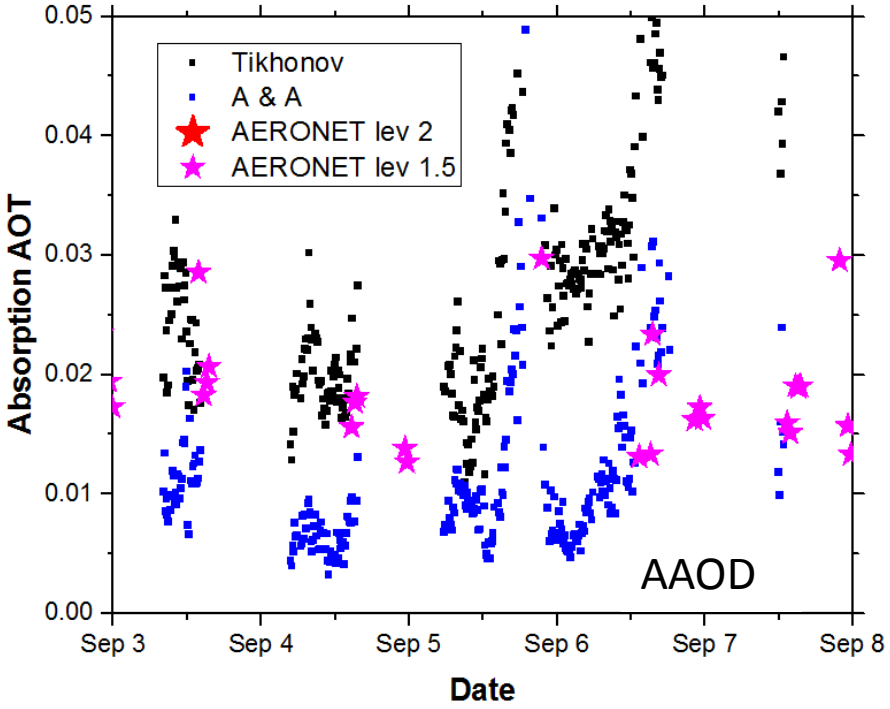


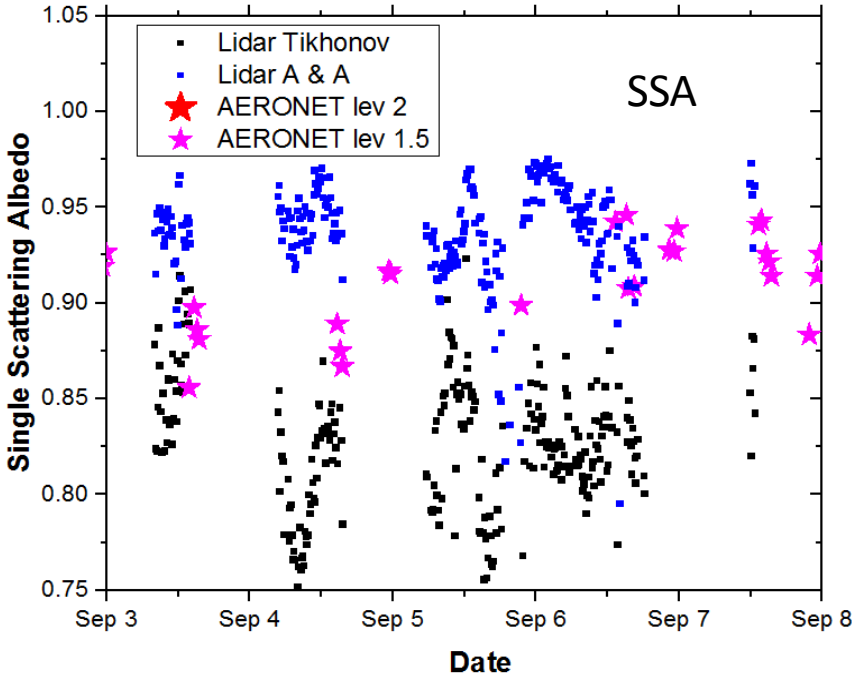


- TiARA expected to give better performance for size and concentration retrievals

Thanks to Rick Wagener for maintaining AERONET site. Thanks to Brent Holben and AERONET team for retrievals

Comparisons of Column Averages with AERONET - Single Scattering Albedo and Absorption AOD





- A&A performs better for absorption retrievals (as expected)
- Can only compare to Level 1.5 AERONET retrievals (No Level 2 since AOD<0.4)

Summary and Status

- CHARMS campaign successfully captured joint Raman and HSRL dataset (July 18-September 30, 2015)
- Aerosol backscatter, extinction profiles (355, 532 nm) produced for entire period – acceptable quality for aerosol retrievals
- Producing accurate aerosol backscatter profiles (1064 nm) is the current rate-limiting analysis step – currently preliminary profiles exist for only Sept. 3-7
- Initial multiwavelength aerosol retrievals performed for Sept. 3-7; column average results appear mostly consistent with AERONET
- Additional retrieval development and evaluations planned

CHARMS demonstrates the potential for (the only) continuous dataset of (unique) vertical profiles of aerosol optical and microphysical properties